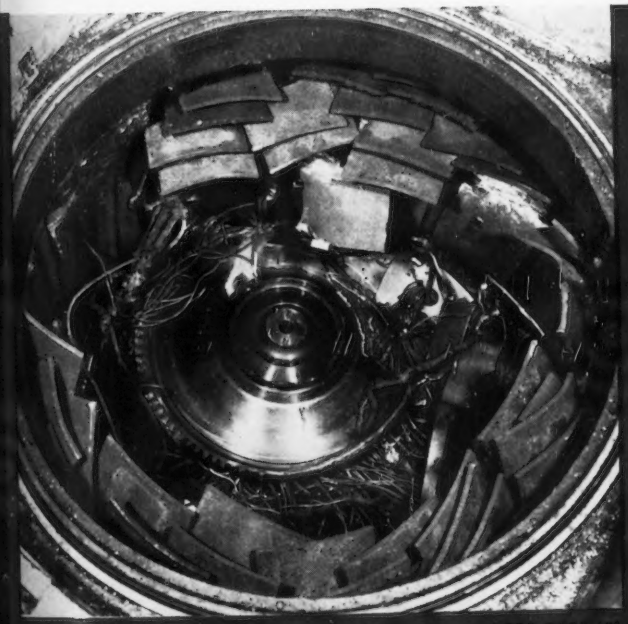
DECEMBER 1961

Christmas Greelings

experimental mechanics



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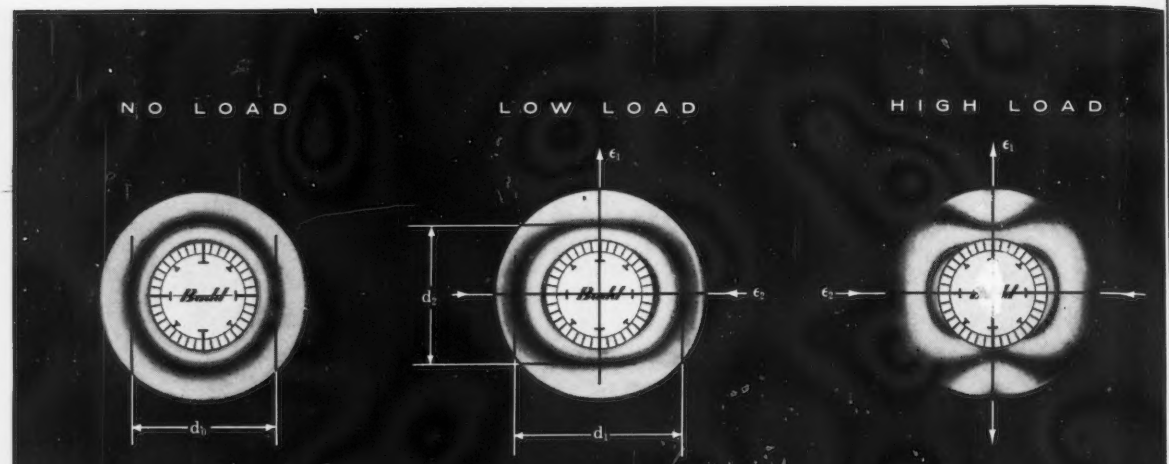
SESA JOURNAL OF THE SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS



NEW! PhotoStress Rosettes* from Budd

THE ONLY GAGES THAT PROVIDE DIRECTLY BOTH ORIENTATION AND SEPARATE MAGNITUDES OF PRINCIPAL STRAINS

*Developed from original circular photoelastic gage patented in France in 1956 by Dr. G. Golubovic of PhotoStress France, U.S. patent pending.

Gages shown actual size. ϵ_1 and ϵ_2 are principal strains. d_o is diameter of circular fringe for zero strain. $d_1 - d_o$ and $d_2 - d_o$ give fringe shift along axes of symmetry of patterns, due to strain. Axes of symmetry are principal strain directions. ϵ_1 is a function of $d_1 - d_o$. ϵ_2 is a function of $d_2 - d_o$.

EXCLUSIVE FEATURES:

- Measures principal strain directions for strain levels as low as 50 microinch/inch and up.
- Major and minor principal strain directions obviously apparent.
- Separate magnitudes of strains obtained directly along desired axis.
- High readout sensitivity due to permanent pattern.
- Constant sensitivity for directions and magnitudes for any strain level.
- Proved PhotoStress technique (Zandman method).

GENERAL FEATURES:

- Direct readout, no instruments or connections.
- Static or dynamic (with strobe light) readings.
- Sensitivity and zero stable with time, unaffected by humidity.
- Easily bonded at room temperature to metals, concrete, wood and other materials.

SPECIFICATIONS:

- Directions of principal strains: within $\pm 5°$ (with care, better accuracies are possible).
- Magnitudes of separate values of principal strains: within ± 40 microinch/inch.
- Packaged 5 gages to the package with cement and complete instructions for installation.

LIMITATION:

- Will not perform accurately in areas of high strain gradients. (Use classical PhotoStress or miniature type MetalFilm strain gages.)

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Other countries: Budd S.A., 10 Avenue de la Grande Armée, Paris 17e, France

RNAL OF THE SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS

experimental mechanics

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SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS
21 Bridge Square, Westport, Connecticut

SESA PUBLICATIONS

PROCEEDINGS OF THE SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS

The PROCEEDINGS are a series of bound volumes comprised of the technical papers presented at National Meetings. These contain the results and descriptions of analytical and experimental investigations, as well as techniques for the measurement of mechanical strain. Published twice annually, they include up-to-date information on various phases of instrumentation. Currently available:

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Volume XVII, No. 1
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CUMULATIVE INDEX—PROCEEDINGS

Thirty-four books of the PROCEEDINGS have been published to date. This Index has been prepared to serve as an easy reference to any one of the 546 papers which have been published in the first thirty books. It consists of three parts: (1) chronological index, (2) author index, (3) topical index. It represents a "master reference file" to all PROCEEDINGS published, from Vol. I, No. 1 through Vol. XV, No. 2.

HANDBOOK OF EXPERIMENTAL STRESS ANALYSIS

This book opens with a thorough presentation of mechanical properties. It presents practical, usable information on: mechanical, electrical and optical gages, brittle coatings, photoelasticity, X-rays, service fractures, analogies, vibration measurements, theory of elasticity and precision of measurements. Stiff cloth binding—contains 1060 pages of text.

MANUAL ON EXPERIMENTAL STRESS ANALYSIS TECHNIQUES

For those who are new to the field of experimental stress analysis, the MANUAL introduces the fundamentals of experimental stress analysis in terms easily understood by the novice. It contains detailed instructions and, with the aid of illustrations and charts, elaborates on the application of three particular methods for determining stress: (1) SR-4 bonded wire strain gages, (2) stresscoat (brittle lacquer) and (3) photoelasticity.

STRAIN GAGE TECHNIQUES

Twenty-three chapters of lectures and laboratory experiments of special summer programs presented at leading universities, covering such topics as: fundamental concepts, selection of gages, basic considerations in strain-gage instrumentation, electrical and mechanical aspects of the gage system, the potentiometric circuit, the wheatstone bridge, amplitude modulation, fundamentals of measuring systems, some commercial systems and rosette analysis. Approximately 680 pages.

EXPERIMENTAL MECHANICS

Official monthly journal of the SESA. Includes technical papers and news items of interest to SESA members and to industry.

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Experimentally Speaking

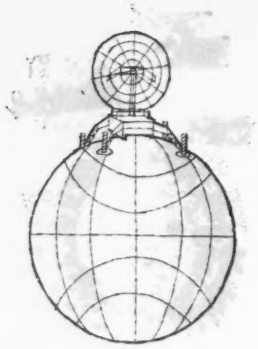
SCIENTIST OR ENGINEER

The enrollment of students in the engineering curriculum of our colleges is decreasing while enrollment in some of the sciences is increasing. Why is there a shift away from engineering? For one reason, many high school students look upon engineering (if they look at engineering at all) as an unsophisticated, nonprofessional, low-level field of endeavor. To them, the engineer may be the street cleaner that works for the Sanitary Engineering Department of the City, or he may be the man who looks after the cleaning of the high school building and who is officially designated as the custodian engineer. Another reason may lie in the information released by industrial organizations, newspapers and magazines. The apparent glamourous space activities are reported as being conducted by scientists, not by engineers. This information leads the high school student to believe that if he wants to work in the field of applied science, he must follow a science curriculum in college which to him probably means physics.

The student who is interested in and has the capacity for the application of science should take an engineering curriculum that will provide a good basic training in solid mechanics, fluid mechanics, thermodynamics, materials science, and electricity and magnetism. In addition, the student must have adequate courses in modern physics and mathematics. There must also be a proper balance of the humanities. This basic training in engineering science may then be followed by graduate work in a field of special interest to the student. This approach is similar to the training given in the medical profession. The basic work in the first four years may be considered as a pre-engineering education. There will continue to be a need for men who are trained for manufacturing and processing operations as practiced by those who have had the standard curriculum in aeronautics, civil engineering, electrical engineering, mechanical engineering, etc.

Practicing engineers and scientists can help by giving the facts to not only the high school students, but also to the high school guidance counselors. Help can be given by providing a clear, accurate picture of the work of the engineer and of the scientist. When an engineering job is done by an engineer, say so. When a scientific piece of work is done by a scientist, say so. Too many industrial organizations believe that they will be more favorably received if the work is reported as being done by a scientist. They think it sounds more sophisticated. Be honest with both high school students and the public. The present trend is driving brains away from engineering or engineering science. Incorrect information will also produce disappointed and confused young men who are not trained to do the things for which they might have the ability or interest had they received the proper guidance.

Donald S. Clark
PROFESSOR OF ENGINEERING
CALIFORNIA INSTITUTE OF TECHNOLOGY



tracking station

the industry in focus

Materials Quarterly Announced

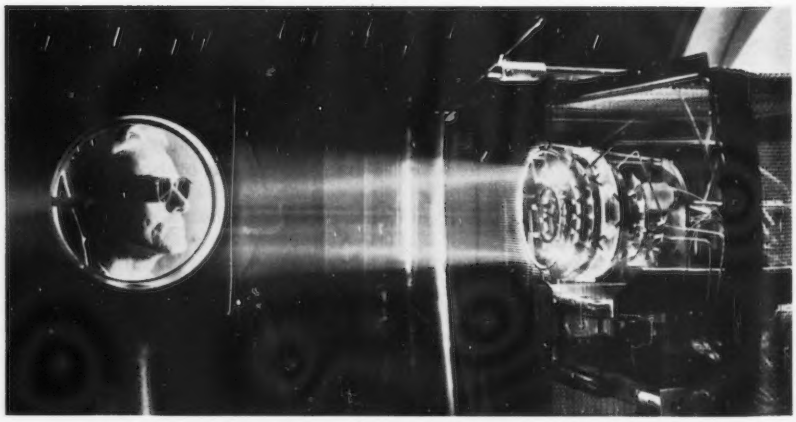
An international quarterly titled *Materials Research* is scheduled to make its appearance in 1962. Original and review articles will be published covering results of research, development of new materials, improvement of service behavior, testing and inspection. While articles will be in English, abstracts will be printed in five languages. To be published in London, England, by Heywood and Co., the magazine's American editor is T. J. Dolan, engineering professor at University of Illinois, Urbana, Ill. Authors are invited to submit papers which fall within the scope of the journal.

Pratt & Whitney Has New Laboratory

A laboratory to develop materials for aircraft, space, and industrial power plants of the future has been established by Pratt & Whitney Aircraft division of United Aircraft Corp.

The new Advanced Materials Research and Development Laboratory will be directed by Maurice E. Shank, former associate professor of engineering at MIT. Principal goals of the laboratory will be development of high-strength materials, alloys for service at extreme temperatures and materials for energy-conversion devices.

Space-probe Power



The eerie glow of ionized atoms shooting out of this working ion engine is viewed by a technician through a porthole in a space simulation chamber at Hughes Aircraft Co.'s research laboratories in Malibu, Calif. Developed by Hughes for the NASA, the engine is the first of a family of such devices which company scientists say may be the ultimate form of propulsion for long trips into space. Although the thrust being tested here is less than a tenth of a pound, a cluster of larger engines operating on the same principle could propel heavy payloads to the farthest planets.

Automation Adds Plant Facility

A new 45,000-sq-ft plant facility in Torrance, Calif., has been occupied by the corporate offices and the Ultrasonics Division of Automation Industries, Inc. The new facility brings the total plant space of the corporation to 175,000 sq ft.

ASTM Changes Name

The name of the American Society for Testing Materials was officially changed to the American Society for Testing and Materials with the signing of a court decree on September 18, 1961, amending the society's charter originally granted in 1902 by the Commonwealth of Pennsylvania. The change emphasizes the society's research work in seeking knowledge of the nature of materials.

B & F Appoints Representatives

The Dana G. Doherty Co. of Needham, Mass., has been appointed by B & F Instruments, Inc. to handle sales in the New England area.

The Rocke International Co. of New York City has been appointed by the Philadelphia concern to handle all sales outside the United States and Canada.

BRI to Become Independent

The National Academy of Sciences—National Research Council has announced that the Building Research Institute, a constituent part of the Division of Engineering and Industrial Research, will become an independent technical society for the building sciences, in late 1962.

Microdot Opens New Sales Office

Microdot Inc., has announced the opening of an Eastern Regional Sales Office in Bedford, Mass., staffed by four sales engineers. Managed by Richard W. Pozzo, the office will handle sales of micro-miniature coaxial, multi-pin, and crimp-type connectors; miniature coaxial cable; Lerco electronic hardware; and associated products.

NOL Computer Simulates Explosions

The U. S. Naval Ordnance Laboratory, White Oak, Md., has developed a motion-picture recording technique that permits "observation" of the interior motions of an explosion which can only be inferred from external photographic records. The technique provides rapid visualization of the solutions to explosion dynamic-and-flow problems obtained with an electronic computer.

Each explosion and shock problem is set up as a grid system in which the intersecting points correspond to positions in the actual explosive system. "Detonation" is effected mathematically and the computer calculates and collects numerical data representing the motion of the grid points. Periodically, the new positions of all the calculated points of the grid system are simultaneously displayed as dots on an oscilloscope screen and photographed in a frame sequence.

Environmental Engineering

The post-war growth of environmental testing as a major research and development tool has generated increased emphasis on the subject in college engineering programs, according to Charles D. Brown, president of MB Electronics, Division of Textron Electronics, Inc.

To equip colleges to better handle environmental engineering education, MB has donated vibration test systems to the University of Southern California, Yale and The Polytechnic Institute of Brooklyn.

Kearfott Moves Sales Office

Kearfott Division, General Precision, Inc., has announced the relocation of the sales office serving the New England area. The office is located at 166 Bear Hill Rd., Waltham, Mass.

Electronics Firm Organized

Organization of Gamma Scientific, Inc., an instrument manufacturing firm of San Diego, Calif., was announced recently

Electronic products, including specialized photometers, will be developed initially to meet the needs of an expanding market for scientific instrumentation, according to Harold P. Field, president.

Marquardt Forms Corporate Division

The Marquardt Corp., Van Nuys, Calif., has established its Facilities Engineering operations as a corporate division and has appointed Malcolm F. McConnell as its director.

The new division will be responsible for facility and associated design projects for both governmental and commercial installations, such as space-environmental laboratories, launching-system complexes and facilities for supersonic, hypersonic and nuclear-propulsion testing.

FUTURE MEETINGS

SESA

MAY 16–18, 1962. Spring Meeting. Sheraton-Dallas Hotel, Dallas, Tex.
OCTOBER 24–26, 1962. Annual Meeting. Hotel Schroeder, Milwaukee, Wis.

ARS

DECEMBER 3–7, 1961. Annual Meeting of American Rocket Society. San Francisco, Calif.

ASTM

JUNE 24–29, 1962. Annual Meeting of American Society for Testing and Materials. Statler Hilton Hotel, New York, N. Y.

AWS

APRIL 9–13, 1962. Annual Meeting and Welding Exposition of the American Welding Society. Hotel Cleveland, Cleveland, Ohio

IAS

JANUARY 29–31, 1962. Annual National Meeting of Institute of the Aerospace Sciences. Hotel Astor, New York, N. Y.

personnel
in the news

STEVER HEADS TWO DEPARTMENTS

H. Guyford Stever, former chief scientist of the U. S. Air Force and professor of Aeronautics and Astronautics at MIT since 1956, is the new head of both the Department of Mechanical Engineering and the Department of Naval Architecture and Marine Engineering.

In his announcement of Dr. Stever's appointment, Julius A. Stratton, president, called attention to the fact that "the appointment of one man to head two departments is not without precedent at MIT, and it in no way means that we are combining the two departments."

Dr. Stever succeeds Professor Joseph H. Keenan in the Department of Mechanical Engineering; Professor Keenan will devote full time to teaching and research. In the Department of Naval Architecture and Marine Engineering, Dr. Stever succeeds Professor Laurens Troost, who retired in 1960 to return to his native Holland.

MORRISON APPOINTED TO RESEARCH POST

S. Roy Morrison, senior staff scientist at the Minneapolis-Honeywell Research Center in Hopkins, Minn., has been promoted to assistant director of the center.

Dr. Morrison succeeds John R. Dempsey, who recently was named director of the center to fill the vacancy created by the resignation of Finn Larsen, now assistant secretary of the Army in charge of research and development.

Dr. Morrison, a native of Saskatoon, Canada, joined Honeywell in 1955 as a staff scientist. He was graduated from the University of British Columbia, received his doctorate in solid-state physics from the University of Pennsylvania and did research at the University of Illinois before starting his career with Honeywell.

H Guyford Stever

KROPMAN NAMED GROUP HEAD

Hans Kropman who joined Datex Corp. several months ago as senior mechanical designer, has been named supervisor of a new Technical Services Group.

The new group will centralize activities formerly performed by individual project teams, and will provide technical support including drafting, mechanical and packaging design and administrative activities.

Mr. Kropman was formerly mechanical engineering supervisor in charge of a system-design department at Collins Radio Co., in Burbank, Calif.

WILDHACK MADE ASSOCIATE DIRECTOR

William A. Wildhack has been appointed an associate director of the National Bureau of Standards. He will be responsible for coordination of NBS measurement services to science, industry, other agencies of the Federal government and the states. These services include consultation and research on special problems of measurement, and calibrations and tests performed on instruments, equipment and materials, and the distribution of standard samples and reference materials.

Since 1960 Mr. Wildhack has been special assistant to the director, exploring the needs of industry and other government agencies for precision standards, calibration services, and improved measurement techniques.

Mr. Wildhack, who received a B.S. in electrical engineering in 1931 and an M.S. in physics in 1932 from the University of Colorado, taught physics and mathematics at that University, at Boise Junior College, and later at George Washington University.

LITTAS JOINS LESSELLS STAFF

Evangelos Littas, naval architect and marine engineer with degrees from both the Naval College, Athens, Greece, and MIT, has joined the staff of Lessells and Associates, Inc., Boston, Mass. For the past two years he has been with the Boston Naval Shipyard where he was responsible for structural design and stress analysis and the measurement and evaluation of shipboard alignment data.

From 1944 to 1956 Mr. Littas was an officer in the Royal Hellenic Navy, assigned to sea duty successively as damage-control officer, engineering officer, gunnery officer, and commanding officer on vessels of many types. For two years he was commanding officer in charge of the naval base at Corfu, Greece.

ELLIOTT NAMED ACADEMIC VICE-PRESIDENT

Martin A. Elliott has been appointed academic vice-president of Illinois Institute of Technology, effective Sept. 1, 1961. He succeeds Joseph C. Boyce who will become vice-president in charge of graduate studies and research.

Dr. Elliott was previously on the faculty of Illinois Tech as research professor of mechanical engineering from September 1952 to February 1956 when he was named to his current position as the director of the Institute of Gas Technology, an IIT

PLAN NOW
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DALLAS, TEXAS

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affiliate. He was born in Baltimore, Md., in 1909, and is an alumnus of Johns Hopkins University where he received bachelor (1930) and doctor of philosophy (1933) degrees in gas engineering.

TAYLOR ELECTED TO BOARD

Philip B. Taylor, formerly assistant secretary of the Air Force for Materiel, has been elected to the board of directors of The Marquardt Corp., it was announced recently.

Mr. Taylor's background spans nearly 40 years of experience in the field of aircraft propulsion systems. After joining the Wright Aeronautical Corp. in 1922 as a test engineer, he subsequently held various positions, including chief engineer, vice-president and acting general manager.

Following his resignation from Wright at the end of World War II, he formed the Taylor Turbine Corp., after obtaining the exclusive right to sell and manufacture the Rolls Royce turbojet engine in this country. In 1946 this license was sold to the Pratt & Whitney division of the United Aircraft Corp.

He became a partner in the engineering and construction firm of Sanderson & Porter in 1947, directing the firm's varied engineering activities. Mr. Taylor was sworn into office as assistant secretary of the Air Force (Materiel) on April 16, 1959, and served until February 1961.

FOUR APPOINTED AS FIELD ENGINEERS

Four field engineers were appointed by E.R.A. Inc., engineering representatives of Great Neck, N. Y. At the same time, Jesse Markson, president of the firm, announced the comp'etion of their new building.

Former engineering professor at CCNY, Mr. Markson was also a design engineer and a consultant for several companies. He is a professional engineer in the State of N. Y., a member of several engineering societies, including SESA, and holds several patents in the field of shock and vibration.

The four engineers recently appointed are: Stuart J. Cohen, formerly reliability engineer for Airborne Instruments Laboratory, N. Y.; Michael Trubowitsch, formerly sales engineer for Markite Corp., N. Y.; Jospeh Ligori, former senior project engineer in the Radio Systems Division of Western Union Co., N. Y.; and Jerry Gold who was with Bendix Corp., Red Bank, N. J., as a design engineer.

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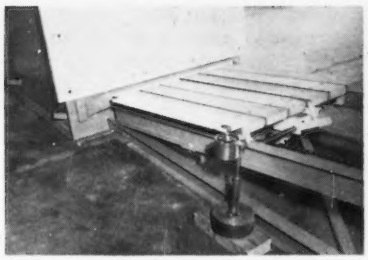
DIRECT-RECORDING OSCILLOGRAPH

A 24-channel, direct-recording oscillograph has been introduced that can be rack mounted in industrial, scientific and aerospace instrumentation systems or supplied in a specially designed case for table or bench use.

The new instrument, which was developed by Minneapolis-Honeywell's Heiland Divison, 5200 East Evans Ave., Denver 22, Colo., is called the model 1508 Visicorder. It fits 24 direct-recording channels into only 7 in. of rack height.

The 24 channels are recorded on 8-in. wide paper, with each channel capable of recording individual static or dynamic phenomena at frequencies from dc to 5000 cps, the manufacturer reports.

All operating controls are on the front panel of the instrument, and any of 12 recording speeds may be selected before or during recording by means of push-button controls. **50**

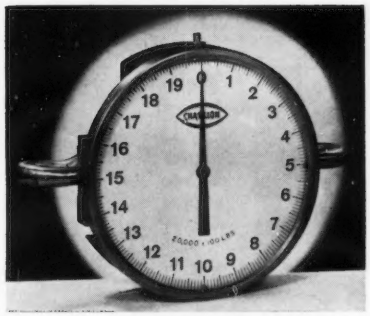


MECHANICAL VELOCITY METER

Developed for use in the package-testing laboratory as a practical, low-cost means of measuring dolly impact velocities of conbur incline impact-testing machines, the Velometer is a compact self-contained mechanical instrument equipped with a calibrated drive unit mounted on the input shaft, it is reported by L.A.B. Corp., 500 Onondaga St., Skaneateles, N. Y. The meter is supported by a weighted pedestal which is placed on the floor near the bottom of the incline track structure and so positioned that it can be actuated as the dolly passes by.

As the dolly contacts the drive unit, the meter's mechanism registers velocity in fps on its dial by means of a resettable maximum speed pointer.

The Velometer allows calibrating a given conbur's operating characteristics in terms of dolly impact velocities for different load and run conditions. **52**



TRACTION DYNAMOMETER

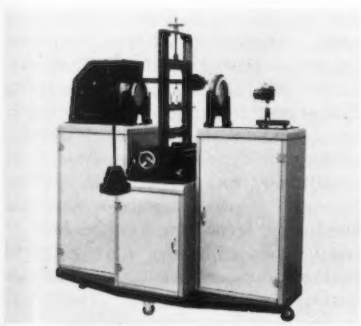
A new traction dynamometer said to have a capacity range of 500 to 100,000 lb with an accuracy of better than one percent has been developed by John Chatillon & Sons, 85 Cliff St., New York, N. Y.

As described by manufacturer, a major design feature of the new model TD-10 is the use of a single pointer instead of the usual two or three. In this model, the pointer will remain at its maximum reading position and will not return to zero until a conveniently located mechanical-clutch button is pressed.

The dial is a full 9 in. and is equipped with 200 graduations. It has bold, black, evenly spaced numbers on a pale-green background for easy readability. The dynamometer can also be supplied with a dial graduated for metric measurement. **54**

new products

For more details regarding these products, circle item number on Reader Information Card



POLARISCOPE

A $5^1/_2$-in. diam polariscope has been placed on the market, recently, by Sharples Engineering Co. (Bamber Bridge) Ltd., Chorley Rd., Walton-le-Dale, Preston, Lancashire, England.

The manufacturer reports that this polariscope has been designed for senior research work in photoelastic stress analysis, university and college lecture purposes and as a practical engineers' tool for the assessment of designs. It is a compact instrument mounted in its own cabinet, which contains ample storage space for models and special loading equipment.

The polariscope is also described as being unique in that provision is made for using it either as a diffused-light or transmission instrument. **51**

AUTOMATIC STOP CLOCK

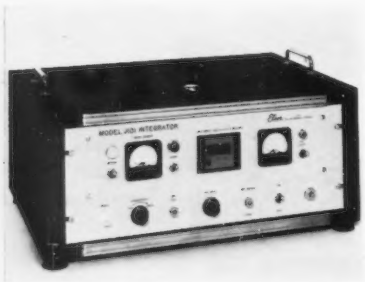
A new automatic stop clock, which measures time intervals down to 1/100 sec and can be started, stopped and reset by remote means, has been developed by Industrial Timer Corp., 1407 McCarter Highway, Newark, N. J.

The new device, Series ESC, features a unique cone clutch which engages the pointer mechanism with the synchronous motor. The clutch engagement is so rapid that no dial compensation is required for pull-in lag, according to manufacturer. The engagement time is between 20 and 40 msec.

The new electric stop clock can be used in laboratories, testing facilities, automatic test equipment, and other applications. **55**

PORTABLE HYDRAULIC COMPRESSION TESTER

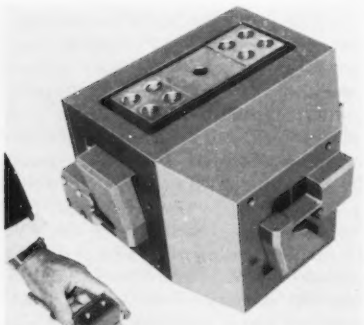
Research Products Co., 1415 3rd St. South, P.O. Box 1047, St. Petersburg 31, Fla., announces the availability of their RPC portable hydraulic compression tester. It is equipped with a micromatic control for sensitive application of pressure, the manufacturer states. The use of seven 6-in. diam dials extend the range up to 0–10,000 lb. It may be used for testing metals, ceramics, plastics, adhesives, electronic parts, etc. Fields of application include research, education and quality control. Weight is only 29 lb and unit is easily carried for demonstration purposes. Further details are given in Bulletin 61-C. **56**



INTEGRATOR

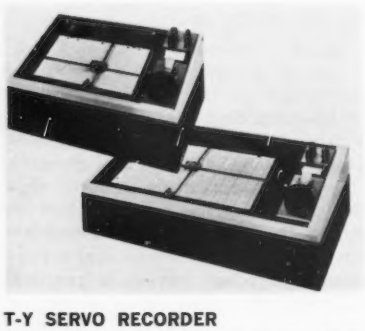
The Model J101B integrator has been developed recently by Elcor, Inc., 1225 W. Broad St., Falls Church, Va. It is reported to be a flexible and accurate instrument for integrating amplified signals derived from various transducing elements which measure, for example: radiation, temperature, displacement, moisture, humidity, light, color, strain, weight, absorption, and many other quantities. It is an analog accumulator. The J101B can be used with current and voltage indicators, recorders, or any other instrumentation that supplies a full-scale output of one ma at a voltage lying anywhere from 10 to 100 v, the manufacturer reports. The instrument is provided with an input adjustment that permits accommodation to the input signal-source voltage.

The integrated information is indicated by means of a 6-decimal digit counter and a $2^1/_2$-in. meter to interpolate between successive values of the least significant figure on the counter. Accuracy is said to be one percent. Drift is less than 0.01 percent per hour. **57**



UNIVERSAL FLEXURE PIVOT

Ormond Inc., 11969 Rivera Rd., Santa Fe Springs, Calif., announces the availability of its largest universal flexure pivot produced to date (rated 400,000 lb). Above photo shows it in comparison with a 10,000-lb model. According to manufacturer, this flexible pivot is a compact, efficient and reliable coupling designed for use in load-measuring systems requiring gimbaled action and accurate calibration about a single point. The universal flexure (model UWF-8) is also said to eliminate redundancy, to reduce interaction, to increase elastic stability, to provide axial rigidity under load, to amplify the resonant frequencies of the system and to require only minimum maintenance. **62**



T-Y SERVO RECORDER

Houston Instrument Corp., P.O. Box 22234, Houston 27, Tex., announces that its new models HR-80 and HR-87 T-Y recorders feature maximum convenience in recording and are designed to replace conventional strip chart and circular chart recorders for all applications where a chart length of 10 or 15 in. will provide adequate resolution. T-Y recorders eliminate the inconvenience of handling and cutting rolls of chart paper and of replotting data. Records on standard graph paper are immediately available for use, reproduction or filing in standard loose-leaf notebooks, the manufacturer explains. Controls permit several parallel records to be run on one chart for comparison. The Model HR-80 is designed for $8^1/_2$ x 11-in. graph paper and the Model HR-87 for 11-x $16^1/_2$-in. paper.

Both the HR-80 and the HR-87 T-Y recorders include a null-seeking servo which moves an ink pen in proportion to a low level d-c input signal on the vertical axis and an inexpensive plug-in synchronous timing motor to move the pen from left to right about the vertical or "Y" axis. **64**

READOUT OSCILLOSCOPE

Tektronix, Inc., P.O. Box 500, Beaverton, Ore., announces that the new Type 567 readout oscilloscope is now available. Adding readout convenience to dual-trace applications, the oscilloscope presents simultaneously an analog display on its 5-in. CRT with a digital presentation on the automatic computing programmer, the manufacturer reports.

Features of the automatic computing programmer are said to include positionable measurement reference zones, automatic normalization, zone intensity markers, automatic and manual start-timing and stop-timing systems, preset-limit selector, provision for external programming. These features—and others in the sampling dual-trace and sampling sweep plug-in units and the oscilloscope itself—enable the Type 567 to measure pulse amplitudes and time increments between percentages of selected amplitude levels on an absolute or relative basis. **66**

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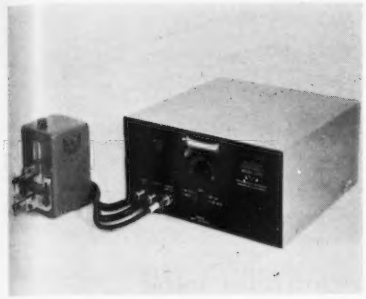


WELDING MACHINE

Model 1059 is a solid-state, capacitor-discharge welding-machine power supply with full circuit switching for each of two ranges. It is decribed by the manufacturer, Weldmatic Division, Unitek Corp., 950 Royal Oaks Drive, Monrovia, Calif., as being essentially two power supplies in one. Maximum versatility in this voltage regulated unit is achieved by rapidly switching from a low range of 0.04 to 9 watt-sec to a high range of 0.2 to 45 watt-sec, as required.

Typical applications include fine whisker-wire attachment to semiconductor leads, microcomponent lead attachment in deposited thin-film circuitry in the low range, and connecting component leads to circuit ribbon in high-density packaging in the high range. **67**

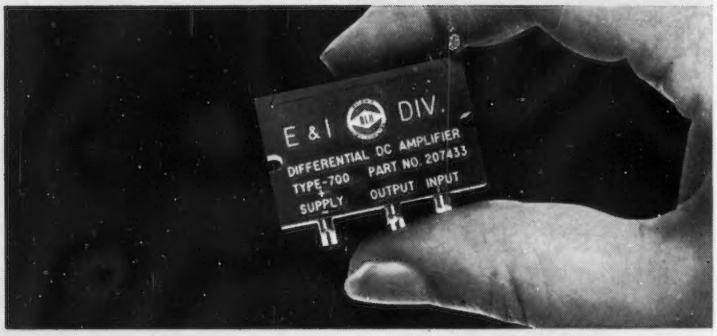
ELECTRONIC TENSION RECORDER

An electronic tension recorder to record tension and its changes during all preparatory operations of wires, cables, tapes, yarns, and cordage, has been added to the line of tension meters offered by Tensitron, Inc., P.O. Box 185, Harvard, Mass.

Said to show quickly-changing tensions electrically during the preparation of wires and cables at full speed, it enables the user to engineer and standardize the best tensions.

Tension is sensed by a hand-held electric tension transducer. By pulling the trigger three prongs are parted. The wire is placed between the two outer contacting pins and the tension feeler. Upon release, the wire is lifted against the inner sensing element, producing electric signals. **68**

NEW BLH MICROMINIATURE AMPLIFIER IS SMALLEST, MOST RELIABLE UNIT AVAILABLE AT ITS PERFORMANCE LEVEL



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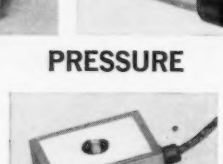

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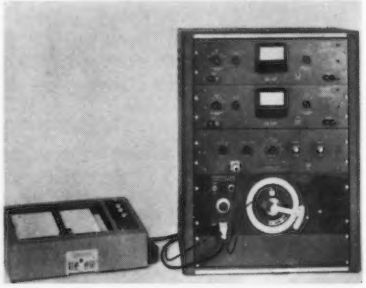
D-C AMPLIFIER MODEL

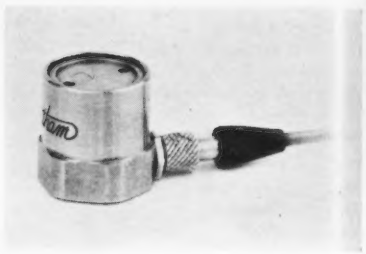
The chopper-stabilized, all-transistor d-c amplifier model 4155 has ±100 ma, ±10 v output for driving high-frequency galvanometers, according to its manufacturer, the Dynamics Instrumentation Co., 583 Monterey Pass Rd., Monterey Park, Calif. It has voltage gain steps from 0.1 to 10.0 (continuously variable between steps), an input impedance of 100 k (constant over the passband), frequency response of dc to 30 kc, and dc drift of less than ±0.1% for any gain setting. **75**



WIDE-RANGE POTENTIOMETER TESTER

A new, wide-range tester has been developed by F. L. Moseley Co., 409 N. Fair Oaks Ave., Pasadena, Calif., to plot and record shaft rotation versus resistance for any single-turn potentiometer easily and accurately with an X-Y recorder.

The new potentiometer tester, Type 2398, supplies X and Y d-c signal voltages, representing shaft rotation and resistance, respectively, to any Autograf X-Y recorder. The recorder then translates these signals into permanent inked graph form in standard fashion. The tester is designed to operate with Moseley Autograf X-Y recorders, but will operate equally well with any X-Y recorder having the same input characteristics as the Autograf, according to the manufacturer. **76**



PIEZOELECTRIC LINEAR ACCELEROMETER

A new miniature piezoelectric linear accelerometer that is said to feature high natural-frequency characteristics, small size, and rugged construction has been introduced by Statham Instruments, Inc., 12401 W. Olympic Blvd., Los Angeles 64, Calif. Model AK105 employs a sensitive "self-energizing" piezoelectric element for reliable and accurate measurements of linear accelerations, the manufacturer states.

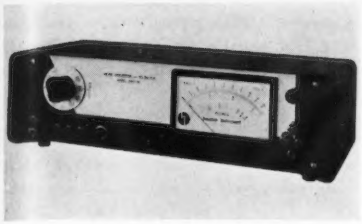
Designed to withstand stringent aerospace environmental requirements, Model AK105 is encased in stainless steel and operates over a temperature range of −65 to +250° F. **77**

HIGH-LOW TEMPERATURE CHAMBER

A new high-low temperature chamber is announced by Bemco Inc., North Hollywood, Calif. Control circuit detects very slight temperature changes within the chamber, and activates a relay which provides either heating or cooling, according to the manufacturer.

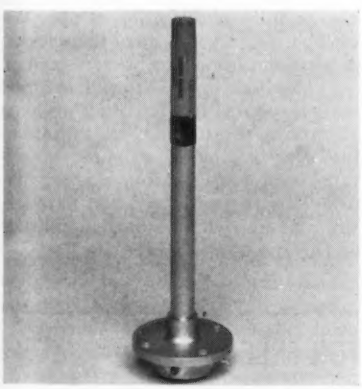
Temperature range is −100 to +600° F. Temperature can be lowered from +70 to −100° F within 5 min, and increased from +70 to +600° F in 45 min. Electric-resistance type heating unit operates on 15 amp at 115 v alternating current. Refrigerant is liquid CO_2.

Manufacturer states that chamber's sealed construction permits continuous operation at −100° F with no condensation forming on the insulation, and no reduction in thermal efficiency. **78**



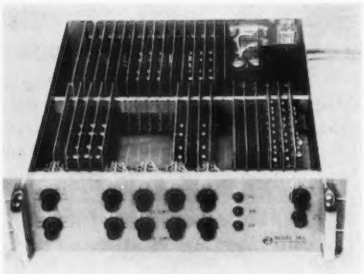
AC/DC CONVERTER-VOLTMETER

Houston Instrument Corporation, P.O. Box 22234, Houston 27, Tex., announces that its new Model HVC-30 ac/dc converter-voltmeter provides 25 microvolt resolution on lowest scale with only 0.5 percent ripple down to 5 cps. A 1 percent panel meter with mirror scale is included for signal monitoring. The instrument may also be used as a 1 percent a-c vacuum-tube voltmeter. Calibration voltages of 0.1 percent are provided on the panel to permit rapid compensation for output loading or long-term amplifier drift. Typical applications include indication and recording of low-level and low-frequency signals as well as those applications handled by conventional ac/dc converters, according to manufacturer. Input ranges extend from 10 mv to 300 v full scale. Input impedance is 10 megohms. For convenience, three output levels are provided, 1 v at 3500 ohms, 0.1 v at 350 ohms and 0.01 v at 35 ohms, all full scale. **80**



VERTICAL SENSING ELEMENT

Kearfott Division, General Precision, Inc., Little Falls, N. J., has announced the production of the C70 1806 002 electromagnetic vertical sensing element, a gravity-sensitive, liquid-damped, pendulous device which can be applied to any vertical sensing situation requiring an electrical output. A frictionless wire-suspended mass acts as the moving portion of two orthogonally mounted differential transformers to provide a phase-sensitive output signal proportional to tilt angle. Utilized in a servo system, it reportedly can initiate self-alignment of a gyro platform or it may be used solely as a true pitch and roll indicator. The unit operates from a standard power supply and is said to have exceptional vertical repeatability, high sensitivity and low null voltage. **81**



DIGITAL COMPARATORS

The NLS 54 and 55 digital comparators, formerly custom built on special order, have now gone into production at Non-Linear Systems, Inc., Del Mar, Calif. Fully transistorized and equipped with mercury-wetted contact relays, the comparators are said by the manufacturer to provide a precise, fast, reliable way to determine if an input voltage or series of voltages is within preset limits. The Model 54 and 55 comparators convert data from digital measuring instruments—such as a-c and d-c digital voltmeters, digital ratiometers, and digital ohmmeters—into go/no-go form. The NLS Model 54 is a four-digit instrument, and the Model 55 is the five-digit version.

Among other applications, the comparators can be utilized for giving audible or visual warnings of abnormal conditions in research and development work, and reliability and environmental testing of systems such as guided missiles. **82**

COAXIAL CONNECTORS

New versions of Type 874 coaxial connectors, including locking cable and panel, and recessed locking-panel types, have been announced by the General Radio Co., West Concord, Mass.

Retaining the hermaphrodite feature of the standard 874's, the new locking connector is fully compatible with the non-locking types. When two locking connectors are mated, the threaded sleeve of either connector is screwed onto the threaded shell of the other. The sleeve of the second connector is backed off to a storage position. **83**

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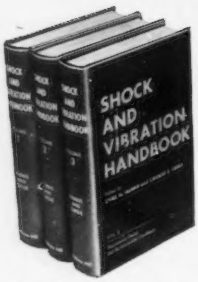

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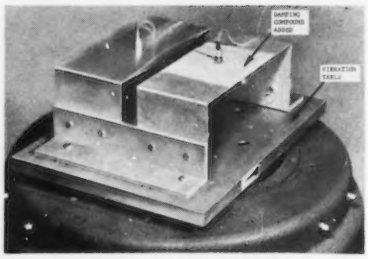


VISCOELASTIC DAMPING COMPOUND

A new, viscoelastic material which, when sprayed or trowelled onto metal plate, drastically reduces structurally borne noise and vibration has been announced by The Korfund Co., Inc., Acoustics and Instruments Div., 48—32nd Place, Long Island City, N. Y. The compound is said to render metal plate almost equivalent to a critically damped structure, as exhibited by low resonant magnification under vibration, and imperceptible ringing under shock.

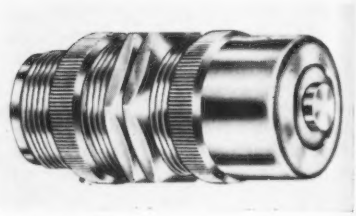
Designated as Korfund "Vibrodamper" compound, this damping material solves the problems caused by severe resonant tendencies of normal structures such as sheet-metal chassis, aircraft structures, and equipment housings, according to manufacturer.

It is also reported that "Vibrodamper" compound is handled like a coat of paint; dries to a smooth, attractive finish; is non-toxic and non-flammable; is resistant to alkali, grease, gasoline, and aliphatic oils; and is unaffected by ozone or sunlight. **84**

DYNAMIC TESTER FOR PLASTICS

The dynamic mechanical properties of plastics may be obtained over wide frequency and temperature ranges with the TMI Maxwell dynamic tester, it is reported by Testing Machines, Inc., 72 Jericho Turnpike, Mineola, L. I., N. Y. This machine applies a sinusoidally oscillating strain to the test specimen. The magnitude of the strain applied can be controlled, making it possible to test over any desired position of the stress-strain curve, according to manufacturer. The Maxwell dynamic tester consists of essentially two parts: a mechanical unit and an electronic control panel for adjusting temperature, testing speed, and with output jack for recorder. The basic theory and certain test results are covered in American Society for Testing and Materials Bulletin No. 215.

A copy of this reprint and an illustrated products specification sheet is available for the asking from Testing Machines, Inc. **85**



DUAL-PURPOSE ELECTROMAGNETIC TRANSDUCER

A newly designed, dual-purpose transducer which can either detect or excite vibrations without contacting the object to be tested, is being produced by Philips of the Netherlands for its sole U. S. distributor, The Korfund Co., Inc., Acoustics and Instruments Division, Cantiague Rd., Westbury, L.I., New York.

The Philips Type PR-9262 electromagnetic pick-up is unique in that it may be used in cases where the object to be measured has so small a mass that any contact with an indicating instrument would influence the vibration, according to Korfund. It also permits investigation of pulsating phenomena. A feature of this pick-up is the absence of any contact resonance.

This lightweight transducer will measure both relative and absolute vibrations, transforming the vibrations into electrical voltages whose magnitude is proportional to velocity. By using the proper integration network, the pick-up will also read amplitude and acceleration of vibrations. **86**

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See Page 17A

Weldable Strain Gages

A new line of weldable strain gages is described in product data sheet No. 4324 published by Electronic & Instrumentation Division of Baldwin-Lima-Hamilton Corp., 42 Fourth Ave., Waltham 54, Mass.

The gages are said to afford electrical stability and high linearity of response over a range of temperatures from cryogenic through 750° F, and offer temperature compensation to ±1 ppm/ °F from 50–250° F.

The data sheet gives illustrations and provides technical information on use of the gages for applications where standard types of strain gages cannot be used. **100**

Digital Data System

A 16-page brochure describing the new MicroSadic digital data-acquisition system is available from Consolidated Systems Corp., 1500 South Shamrock Ave., Monrovia, Calif.

The brochure, bulletin 3047, provides a technical introduction to MicroSadic, an integrated, high-speed, general-purpose solid-state system capable of sampling several hundred channels of analog data at up to 15,000 samples per sec, according to the manufacturer. The system converts analog information to equivalent digital form and records it on magnetic tape in either binary or binary-coded-decimal mode.

The brochure presents a brief functional description of all of the system's major components and includes detailed system specifications. **102**

Data-acquisition System

A 10-channel analog-to-pulse duration system is described in detail in a folder issued by the manufacturer, Genisco, Inc., 2233 Federal Ave., Los Angeles 64, Calif.

The Genisco APD unit is described as a data-acquisition system for precision applications in process control through direct digital conversion of analog input from d-c sensing devices. The new 4-page folder, explains operation and capabilities for use with thermocouples, resistance thermometers, or strain-gage transducers to monitor, record or control temperature, pressure, stress or voltage. The publication includes a block diagram of a typical temperature-monitoring application along with performance specifications. **104**

Automatic Data Logger

A bulletin (D 401) released by The Bristol Co., Waterbury 20, Conn., is written to alert potential users to the economy and application flexibility of Data-Master automatic data loggers. Clear photographs supplement discussion of operating-system installations in research, manufacturing, distribution and process industries. **108**

Surface-temperature Transducers

Trans-Sonics, Inc., P.O. Box 328, Lexington 73, Mass., offers Special Product Note 2342 in which its "Tanatherm" interchangeable surface-temperature transducers are discussed in detail.

Tanatherm transducers, the manufacturer states, are designed for installation on smooth surfaces which cannot be mechanically disturbed or subjected to heat. Supplied with room-curing "Red Cerro" cement, the elements may be quickly and conveniently applied. Having nickel or platinum elements and trimming windings, the Tanatherms' interchangeability permits their use in multipoint temperature-measuring systems utilizing Trans-Sonics bridges and power supplies, according to the manufacturer. **110**

Sonic Electronics

A 4-page folder gives short, clear descriptions of, and brief specifications for, numerous models among six types of sonic equipment manufactured by H. H. Scott, Inc., Instrument Division, 111 Powdermill Rd., Maynard, Mass.

The equipment includes laboratory amplifiers, random-noise sources, laboratory loud-speaker systems, FM broadcast monitors, alarm-control systems, and sound-measuring and analyzing instruments. Detailed bulletins are available for each of the models. **112**

Stress-strain Gage with Built-in Computer

A bonded-resistance foil-type stress-strain gage is described in a product data sheet published by Electronics & Instrumentation Division of Baldwin-Lima-Hamilton Corp., 42 Fourth Ave., Waltham, Mass.

The data sheet provides information on the use of the stress-strain gage as a simple and automatic computing device which solves stress-strain equations without complex calculations by the user.

The gage incorporates two separate axial strain-sensing elements oriented 90 deg apart so that it can develop an electrical response proportional to either stress or strain at the user's discretion.

Each element may be observed independently for conventional strain measurement, or together to produce readings that are proportional to stress along the principal axis, the manufacturer explains. **114**

Metal Crystal Growth

The growth kinetics of zinc, potassium and mercury crystals are being investigated in a basic research program of metal physics at the National Bureau of Standards. Thus far, experimental results obtained from growth measurements of zinc crystals support the screw-dislocation theory rather than the surface-nucleation theory of the crystallization process. The crystals, nucleated and grown in experiments on a tungsten rod, formed in the shape of truncated hexagonal pyramids.

For further information on this program, write to NBS Office of Technical Information, Washington 25, D. C.

Decade Counter

A two-page bulletin describing their Model T-268 decade counter is now available from Avtron Manufacturing Inc., 10409 Meech Ave., Cleveland 5, Ohio.

The Avtron decade counter units are general-purpose plug-in, high-speed, electronic digital counters with column display to indicate the number of the last pulse received. With a count of ten, the counter gives an output pulse of one and resets itself to 0, thus any count may be obtained by cascading the units side by side so that the first counter provides "units" the second "tens" and, etc. The total count appears as a number across the row of counters. Cutting off input pulses stops the counting operation; however, the last display can be held until the counters are reset with a signal fed from the associated circuitry. Special outputs are available for remote readouts, digital recorders, digital-to-analog converters, printers, etc., according to manufacturer. **117**

A Note to AUTHORS

- All papers and technical notes should conform to style requirements set forth in the manual "An SESA Paper" and the "Authors' Check List." Obtain your copies from SESA Headquarters, 21 Bridge Square, Westport, Conn.
- All papers and technical notes must be reviewed and accepted by the Papers and Proceedings Committee in order to qualify for publication.
- Authors must provide a statement that their articles have not been previously published nor submitted for publication elsewhere.
- One original and two copies of the manuscript, complete and carefully typed with double spacing and wide margins, are to be sent to: Dr. Roscoe Guernsey, Chairman, Papers and Proceedings Committee, Space Technology Laboratories, Inc., One Space Park, Redondo Beach, Calif.
- Authors should state their affiliation, title or position and mailing address.
- All papers, but not necessarily technical notes, must be presented at a Society Meeting either orally or by title.
- If at all possible, length of text should not exceed 4000 words; a technical note should not contain more than 750 words.
- Illustrations must be clearly drawn in ink and should not be larger than $8\frac{1}{2}$ x 11 in. "Guided" lettering should be used at all times and should be large enough to be legible when reduced. Photographs must be sharp, glossy prints. A separate list of captions for all figures must be typed with double spacing. The figure number and author's name should appear on the back of each illustration.
- Reprints may be ordered from SESA Headquarters.

Industrial Instruments

Barton Instrument Corp., 580 Monterey Pass Rd., Monterey Park, Calif., manufacturer of instruments for the measurement and control of flow, liquid level, temperature, differential and absolute pressures, has released a new edition of their Gl-4 industrial instrument bulletin. Included are product descriptions and specifications on the complete line of meter bodies, indicators, recorders, switches, transmitters, controllers and integrators.

Also included are basic data on the application of industrial instruments; when a bellows-type meter is superior to a mercury type; why certain meters can be overranged and others cannot; plus other information pertinent to the field of industrial instrumentation. **118**

Optical-plant Survey

A 16-page brochure describing facilities and products is offered by the Photo-Optical Division of Consolidated Systems Corp., 1725 South Peck Rd., Monrovia, Calif.

Consolidated Systems Corp. is an associate company of Allis-Chalmers, Bell & Howell and Consolidated Electrodynamics Corp.

The colorfully illustrated brochure describes the military camera, photo instrumentation and optical production capabilities of the Photo-Optical Division, which is also active in the development of electro-optical and infrared devices. **120**

Analytical Instruments

A new 28-page catalog titled "Norelco X-ray Analytical Instrumentation," containing specifications and operating data on seven key instruments for research and production control, is available from Philips Electronic Instruments, 750 S. Fulton Ave., Mount Vernon, N. Y.

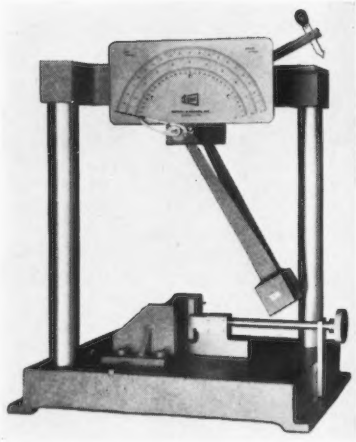
Booklet describes electron probe micro-analyzers; automatic X-ray spectrographs, 100 kilovolt constant-potential X-ray spectrographs, portable X-ray spectrometers, standard vacuum X-ray spectrographs, X-ray diffractometers, X-ray diffraction units and cameras.

In addition to the seven major instruments, the brochure provides details on many accessory pieces of equipment including illuminators and film-measuring devices, film punches and cutters, several different diffraction cameras, pole figure and high-temperature attachments, wide-range goniometers and a variety of specimen holders and assemblies for air, helium or vacuum in the X-ray path. **122**

BOUND VOLUMES OF PROCEEDINGS AVAILABLE

Still available are a number of bound volumes of the series **Proceedings of the Society for Experimental Stress Analysis.** Published twice yearly, these volumes comprise the technical papers presented at national meetings and contain the results and descriptions of analytical and experimental investigations, as well as discussions of techniques and instrumentation studies.

Price per copy: $7.00 to nonmembers and $6.00 to members; plus postage. Copies may be ordered through the Society for Experimental Stress Analysis, 21 Bridge Square, Westport, Connecticut.



Impact Tester

A free reprint of a new test method for tensile-impact energy for plastics and electrical insulating materials published by the American Society for Testing Materials may be obtained from Testing Machines, Inc., 72 Jericho Turnpike, Mineola, N. Y., together with a copy of a brochure illustrating and describing an impact tester used for the test.

This testing machine also performs Izod and Charpy impact tests for plastics and ceramics. A special option available for this machine is motorization with remote control console for use in hot cells for testing radioactive specimens. **124**

Hot Spin-and-burst Test Methods for Aircraft Turbine Wheels

Disk-strength investigations feature suspension-shaft vibration damping, automatically controlled induction heating through radiation pyrometers, rotating-disk temperature measurement, and unattended operation with a safety-interlock system

by A. G. Holms and A. J. Repko

ABSTRACT—Methods are described for suspension-system vibration damping, automatically controlled induction heating through radiation pyrometers, rotating-disk temperature measurement, and unattended operation with a safety-interlock system.

Introduction

Experimental investigations of the strengths of aircraft gas-turbine wheels have been run in special hot-spin test facilities and in operating engines. The purpose of this paper is to describe some hot-spin test facilities and techniques that have been used by NASA. The experimental alternative to special spin-test facilities is engine testing. For comparison with spin-pit testing, engine testing is described by Saldin and DeHuff[1] as follows:

"An analysis was made of the advantages and disadvantages of running bladed disks in an actual engine. These are:

"*Advantages*

1. Represents identical conditions to normal engine running.
2. No additional equipment needed.

"*Disadvantages*

1. Optimum personnel safety is difficult and costly.
2. Costly engine damage in case of a wreck.
3. Rotational speed limitation by other engine parts.
4. High operating cost.
5. Temperature measurements difficult.
6. Design and configuration inflexible.
7. Little independent control of variables.
8. Excessive change-over time.
9. Difficulty in repeating test conditions and results.
10. Measurement of creep is difficult without excessive engine teardown."

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Paper was presented at 1959 SESA Annual Meeting held in Detroit, Mich., on October 21–23.

In comparison, the disadvantages listed by Saldin and DeHuff for engine testing become the advantages of a well-designed hot-spin test facility.

A method of spinning and a method of heating are required for hot-spin testing. Torque for spinning is usually supplied by small turbines operated on air or steam.[2, 3] Electric motors have also been used.[4] For any drive, the required torque is reduced by spinning the test wheel in an evacuated chamber. Two methods of heating have been proved useful, namely, radiation heating as in Ref. 1 and induction heating as in Ref. 5.

The NASA techniques to be described used air turbines and induction heating. The techniques were developed for short-time burst tests of small disks,[6] constant-speed blade-fastening endurance tests[7] and short-time burst tests of engine-size wheels.[8] In these investigations the disk-strength research was emphasized above facilities research. The methods may not be the optimum that further investigation might develop but they do represent ways and means of solving certain difficult problems. The work was done at the NASA Lewis Research Center, Cleveland, Ohio.

Spinning

Air Turbines and Air-turbine Bearings

Rotors were spin tested while suspended from air turbines that supplied the required torque. The turbines were designed by the General Electric Co. and, in many respects, were based on turbosupercharger experience.[9] The turbines were made by the Barbour Stockwell Co., Cambridge, Mass.

Because the test rotor is suspended from the air-turbine, the air-turbine bearings impose limitations on the test-rotor weight, speed and operating time. These limitations depend on the bearing design, lubrication and manner of loading. Bearing tolerances were always specified as ABEC Class 5. The bearings were always replaced when turning by hand produced a feeling of roughness, or after any evidence

of shock loading such as a failure of the test-rotor suspension shaft.

Two sizes of air turbine were used. Size designations refer to the diameter of the air-turbine rotor. A 4-in. size was used for spinning small disks at relatively high speeds, and an 8-in. size was used for spinning heavier wheels at lower speeds. The 4-in. turbine was provided with an adaptor ring so that it could be mounted interchangeably with the 8-in. turbine.

The 4-in. turbine was designed for speeds up to 60,000 rpm and test rotors weighing up to 200 lb. Data for the small-disk burst tests of Ref. 6 were obtained with this turbine. No tests were interrupted by bearing failures.

Bearing failures did interrupt some of the tests with 8-in. turbines. The 8-in. turbine was designed for testing rotors weighing 1000 lb at speeds up to 25,000 rpm with lower speed limitations for rotors weighing up to 3000 lb. The 4-in. turbine bearing carried the entire weight of the test rotor. In contrast, the 8-in. turbine was equipped with a balance piston that could carry some or all of the gravity load of the test wheel. Eight-in. turbines were used for the blade-fastening endurance tests of Ref. 7 and for the large-wheel bursts of Ref. 8. In preliminary blade-fastening tests, air pressure on the balance piston was adjusted to remove all thrust load from the thrust bearing. With the zero-thrust load, bearings failed at speeds of 17,520 and 18,640 rpm. Resulting damage required replacement of many of the air-turbine parts.

The use of balance air was abandoned for the blade-fastening tests. The balance air had also been used to return lubricating oil to the oil reservoir. This function was performed by an oil scavenge pump inserted between the turbine sump and the oil reservoir. The thrust bearing then carried the weight of the test wheel, which was about 30 lb. Subsequent to eliminating the balance air, a total of 4000-hr running time was accumulated for the blade-fastening endurance tests with no failures starting in the bearings. The 30-lb gravity end thrust may have restrained some vibration or slippage of the bearings, thus increasing their lives. Large-wheel burst tests were always run with a balance piston force of 50 to 100 lb less than the weight of the test rotor.

An 8-in. turbine was modified by replacing the number 306 ball bearing with a number 311 angular-contact ball bearing. This turbine was used for slow-speed tests of extra-heavy rotors. It was used to drive a rotor weighing 4800 lb at 4320 rpm. The balance piston of the turbine was pressurized at 21 psig to provide a net bearing load of 4590 lb. The turbine was operated on steam with some heating of the parts. The thrust bearing was at 205° F at the start of rotation. At 4320 rpm, the bearing had warmed to 245° F. No bearing failures occurred.

TABLE 1—SPIN-PIT VACUUM PUMPS

Motor, hp	Rated sealed inlet vacuum, mm Hg	Displacement, cfm	Spin-pit volume, cu ft
5	0.010	100	45
15	0.010	311	106

Speed Measurement

Two magnetic pickups furnished with the air turbine were used for speed sensing. A pickup consisted of a coil wound on a U-shaped permanent-magnet core. A suitable coil consisted of about 4000 turns of 0.0073-in. diam enameled copper wire having a resistance of about 175 ohms. The poles of the core were located within 0.050 to 0.060 in. of projections on a hub of the air-turbine rotor. During a spin test, the projections varied the flux in the core and generated voltages in the coil. Five projections on the air-turbine hub produced five impulses per revolution so that division of the frequency meter readings in cycles per second by 5 and multiplication by 60 gave the rotational speed in revolutions per minute.

Two speed-sensing coils were always used. They were connected to a pair of frequency meters. Induction-heating machines (described later) operated at a frequency of 10 kc and produced false meter readings. The induction-machine frequency was well above the operating frequency of the speed pickups, and the interference was eliminated by high-frequency cutoff filters at the inputs of the frequency meters. Direct-current output voltage (proportional to frequency) from one of the meters was applied to an overspeed safety trip. Tripping of the relay closed a solenoid valve in the air-turbine supply line. Direct-current output voltage from the other frequency meter was applied to a strip-chart recorder in the case of short-time tests, or to an automatic speed-control system in the case of the blade-fastening endurance tests.

Failure speed for all the wheels of Ref. 6 and for the early tests of Ref. 8 was observed by noting the reading of frequency meters just prior to hearing a wheel burst. Other noises in the laboratory were quite distracting and more direct evidence of failure was provided by a special electrical system.

This electrical system used a helical coil (Fig. 9) that surrounded the spinning test wheel. The blade-

TABLE 2—SOME SPIN-PIT CONDITIONS AT WHEEL TEST SPEEDS

Test wheel	Turbine inlet pressure, psig	Pit pressure, mm Hg abs	Test speed, rpm	Rate of speed increase at top speed, rpm/min
J35-1	108†	4.5	13,200	240
J47TK-2	120†	1.0	12,972	680
Extra heavy*	158‡	0.3	4,320	14

* Weight 4800 lb, diameter 70 in., moment of inertia 6570 (lb) (in.) (sec.)^2

† Operated on air.

‡ Operated on steam by Thompson-Ramo-Woolridge at North Perry, Ohio.

fastening failures of Ref. 7 and the latter wheel bursts of Ref. 8 were signaled by the interruption or grounding of the coil. The signal from the coil was used to shut off the turbine air supply and to sound a horn for the large-wheel burst tests or to shut down the entire system including an elapsed-time meter for the constant-speed blade-fastening tests. A digital-reading pulses-per-unit-time meter was found especially convenient for reading burst speeds and for checking the calibrations of the frequency meters.

Evacuation of Spin Tanks

Vacuum pumps were used to reduce the pit pressures and thereby reduce the air friction or windage losses of the test rotors. Ratings of the vacuum pumps are given in Table 1. The air turbines described provided sufficient torque to spin the wheels of Refs. 6 and 7, even in the presence of minor air leaks to the vacuum chamber. The large-bladed wheels of Ref. 8 provided considerably more windage and, with air-turbine torque limited by a 125-psig air supply, the minor air leaks became a limiting factor. Poor vacuum and high windage resulted in poor acceleration with greater probability of test-equipment failure before the wheel burst. Each large-wheel burst test was preceded by careful sealing of leaks. Some data on spin-pit conditions and maximum accelerations at test speeds are given in Table 2.

Suspension Systems

Spin-pit installations commonly use a flexible shaft between the air turbine and the test rotor. Shaft vibration is controlled by a damper system. A rigid shaft and bearing system is described in Ref. 10. NASA used flexible shafts and considerable damping. The small disks of Ref. 6 were suspended from the turbine by a 0.250-in. diam shaft. The room-temperature tests used solid shafts, whereas the hot-spin tests used the same outside-diameter shaft with a 0.125-in. diam central hole. The shaft was 18 in. long. Such a shaft can have many modes of vibration and associated critical speeds. The vibrations were damped by installing the shaft through a stack of felt washers. The washers were $^1/_4$ in. thick and were tightly packed along an 8 in. length of the lower end of the shaft. The inside diameter of the washers was a close fit on the shaft and their outside diameter was a close fit with the housing. The tight packing provided resistance to radial vibrations of the shaft.

The 8-in. air turbine was originally furnished with a shaft-vibration damper similar to that shown by Fig. 1. The shaft used with the 8-in. air turbine was always $^5/_8$-in. OD and $^1/_4$-in. ID. Some tests of J35 wheels resulted in shaft failures. Preliminary blade-fastening tests used automatic balancers, catcher bearings with $^1/_4$-in. radial clearance, or lubricated bearings that provided a rigid mounting for the test wheel. None of these arrangements were adequate. All attempts to restrain the disk were

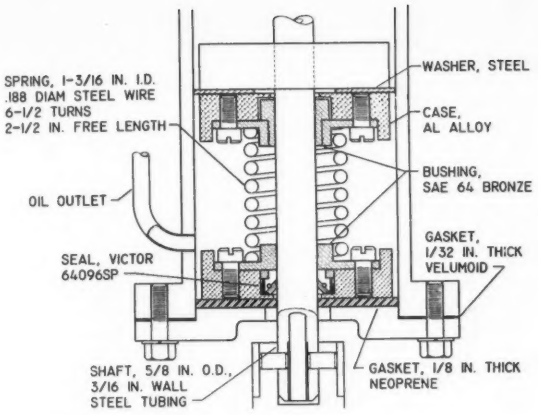


Fig. 1—Details of shaft-vibration damper used with 8-in. air turbine

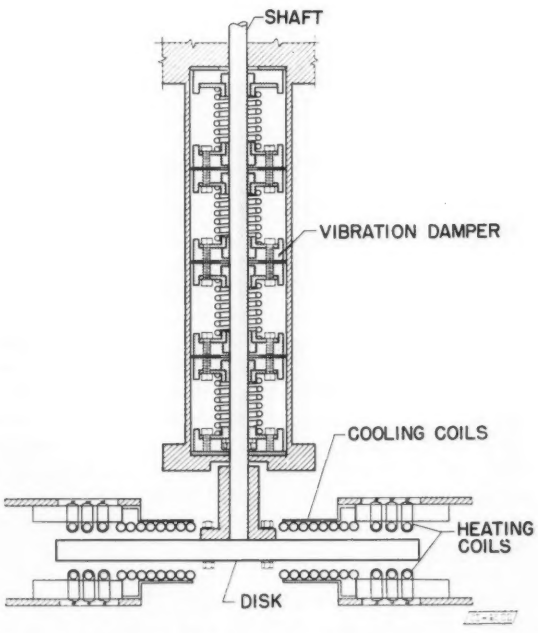


Fig. 2—Arrangement of disk, shaft, shaft-vibration damper, and heating and cooling coils for endurance tests of blade fastenings

abandoned and the final system employed the damper module of Fig. 1 four times as shown by Fig. 2. The original damper used oil pressure to augment the spring force. When four damper modules were used, the normal forces had to be furnished entirely by springs and much heavier springs were used.

Details of the final damper were as follows: the SAE 64 bronze bushings (Fig. 1) were reamed at assembly to have a close sliding fit with the shaft. (A "run-in" period of 1 hr at 1500 rpm usually preceded operation at high speed.) The bushings were securely bolted to aluminum cases (Fig. 1). The nominal radial clearance between the aluminum-

alloy case and the housing was about $^3/_{16}$ in. so that fairly large vibrations could occur with only frictional restraints. The springs were compressed to 60% of their free length at assembly. The force of the springs pressed the aluminum cases against steel washers that were located between each pair of aluminum cases. The steel washers cleared the inside diameter of the housing by only 0.020 in. so that lateral motions of the shaft caused horizontal sliding between the aluminum cases and the steel washers. The damping was provided by this sliding between surfaces pressed together by the springs.

The free shaft motion allowed by the damper system often permitted the test wheel to rotate about the new mass center following a blade-fastening failure. Failure of the shaft was a random occurrence following such fastening failures. Shafts survived blade losses that would have produced forces in the range of 8 tons if the disk had continued to rotate about the original mass center. Such a calculated force actually means that the damper system allowed the mass center to shift 0.037 in. The same damper system was used with the cermet-blade tests of Ref. 11. In 75% of the cases, the damper system permitted the shaft to survive blade-root failures averaging 19,000 rpm, corresponding to calculated unbalanced forces of 18 tons. For the cermet-blade tests, a relatively heavy disk was used and the shift of mass center corresponding to a blade failure was 0.025 in.

The damper housing was located below the spin-pit cover plate in the evacuated spin pit. An oil seal was needed around the rotating shaft to prevent loss of the damper lubricating oil to the vacuum chamber. The location of the seal is illustrated by Figure 1. The sequence of research programs going from short-time room-temperature tests to short-time elevated-temperature tests to long-time elevated-temperature tests represented increasingly severe requirements on the oil seal. Some leakage was generally experienced especially following operation with severe shaft vibrations. Changes were made in seal materials and design (Table 3) as increasingly severe operating conditions were encountered. These seals were uniformly marginal but generally adequate.

TABLE 3—OIL TO VACUUM SEALS

Type of disk test	Shaft diam., in.	Seal	Material
Room-temperature disk burst tests*	0.250	Garlock "Klozure" G. P. 1-X†	Neoprene rubber
Elevated-temperature disk burst tests*	0.250	Garlock "Klozure" G. P. 1-X†	Silicone rubber
Elevated-temperature large-wheel burst tests ‡	0.625	Victor 60096§	Neoprene rubber
Blade-fastening endurance tests‖	0.625	Victor 64096 SP§	General Electric silicone rubber

* Speeds up to 42,000 rpm.
‡ Speeds up to 13,000 rpm.
‖ Speeds up to 20,000 rpm, time periods up to 1000 hr. In some cases two stacked seals were used.
† Equipped with cantilever leaf springs around circumference.
§ Equipped with tension "garter" spring around circumference.

Burst Protection

The spin-pit structures consisted of an outer steel shell with welded joints so that a good vacuum could be obtained. Cover plates and top decks were designed to limit deflections following evacuation. Assured protection of the vacuum shell from wheel fragments was generally provided by multiple-layer concentric rings. These rings were often made of $^1/_4$-in. thick steel laminations to a total thickness of 4 in. Such rings were regarded as permanent spin-pit equipment and other material (regarded as expendable) was put inside the rings to absorb the energy of the bursting wheel.

Damage from the bursting wheels diminished the energy-absorbing ability of the expendable material, requiring frequent replacement. The expendable material for the small-disk bursts was $^1/_2$-in. hot-rolled steel plate formed into a set of six loosely fitting concentric rings. Fragments from the four piece bursts penetrated two or three of the inner rings and produced deformations in the others.

Energy from the large-wheel burst tests was absorbed by expendable material consisting of vertical slabs of hot-rolled $^1/_2$-in. plate loosely stacked to a thickness of 1 or 2 ft. The wheel fragments penetrated three or four of the slabs and bent many others. Other investigators have reported much larger penetrations following similar large-wheel bursts. Perhaps the loose packing increased the energy absorbed by the bending of the plates while minimizing the penetration.

The welded composite wheels failed by throwing off a small segment. The remainder of the wheel then continued to race around the pit until its rotational energy was dissipated. The insertion of a large amount of scrap copper tubing in the bottom

Fig. 3—Use of scrap copper tubing in absorbing rotational energy

of the pit effectively damped the rotation of the wheel (Fig. 3), leaving the fracture surface in good condition for the metallurgical studies of Ref. 8.

Although spin-pit side walls are usually made strong enough to protect operating personnel from wheel bursts in the plane of the wheel, the operation of a spin pit involves other hazards. As examples, one of the tests of large wheels resulted in a failure of the slip-ring set with one part being catapulted against the ceiling. Another test of a large wheel, using an undesirable type of suspension system, lifted the $1^1/_4$-ton cover plate of Figs. 9 and 12 against 12 tons of atmospheric pressure and, in so doing, broke the welds of eight $1^1/_4$-in. diam studs of the type of Figs. 3 and 12. Although not experienced at NASA, one operator noted an explosion within the whirl pit that lifted the cover plate and scattered parts around the plant. The explosion was attributed to a chemical cracking reaction of oil mist started by the hot wheel. In view of such unexpected accidents, the spin pit and auxiliary machinery are best located in a room separate from that containing the instruments and controls. This arrangement also isolates the distracting noises of the equipment.

Heating

Comparison of Induction and Radiation Heating

Heating methods that have been used for hot-spin testing have consisted of induction heating as in Ref. 5 and radiant heating as in Refs. 1 and 4. The advantages of radiant heating are that the initial investment may be lower and that blade heating may be more practical. (Some very limited data on blade heating by induction will be given in the next section.) The NASA research required only heating of the disk, and induction heating was used.

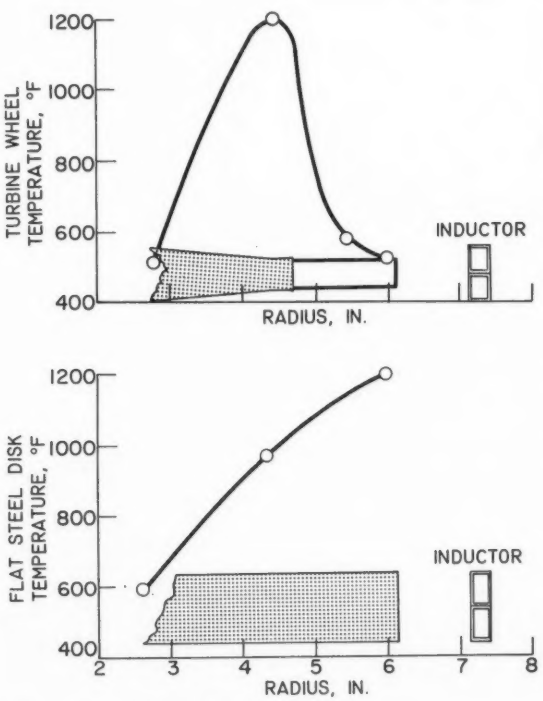


Fig. 4—Temperature distributions, preliminary investigation of induction heating

Three advantages of using induction heating are:

1. The testpiece is heated at internal points and no heat-transfer time delays are involved. This fact is an advantage in tests involving rapid temperature cycling.

2. Depending on the frequency of the alternating current and on the design of the coil, induction heating may be used to introduce the heat in a very small region of a disk. Suitable cooling of the rest of the disk can then produce steeper equilibrium temperature gradients than could be achieved with a radiation furnace.

3. Design of the spin pit is easier. Induction heating makes the test wheel the source of the heat. All spin-pit parts can then be operated cooler than the test wheel. Radiation heating requires a furnace type of structure or other insulation to protect the spin pit from heat that never enters the test wheel. A radiation-heating furnace could be extensively damaged by a wheel burst. The entire damage to an induction-heating system consists of the loss of some insulator blocks and a few feet of copper tubing.

Preliminary Investigation of Inductive Heating

Preliminary tests of induction heating for spin pits were performed at Ohio Crankshaft, Tocco Division, prior to purchase of the machines. Results were as follows:

A General Electric Type B turbosupercharger wheel was spun at 1000, 2000 and 3000 rpm in inductive fields of a coil energized by 0, 5, 15 and 50 kw of 10-kc alternating current. No change in speed occurred, and the hypothesis was accepted that the inductive field does not create net torque in the wheel.

Coil induction currents and disk eddy currents are concentric but opposite in sign so that radial magnetic forces are present, tending to separate the disk from the coil. These forces were sufficiently symmetrical so that the position of the rotating wheel was not disturbed. For a $12^1/_4$ in. diam disk heated to 1200° F, the manufacturer calculated a radial stress in the wheel of 8 psi. Such a stress could not be a significant variable in the destructive tests of rotating wheels. Subsequent disk-strength research programs could not have involved significant magnetically induced stresses because the induction-coil structures were too flimsy to induce significant forces in the test wheels.

Protection of the copper induction coils from excessive temperature was attempted by connecting the coils to a source of air at 80 psig. The coil heated rapidly under small electrical loads, and this method of cooling was abandoned. The final spin-

pit installations used water cooling. Water-flow switches were connected in the induction-coil drain lines. Interruption of the water flow by a wheel burst operated the switch and closed a solenoid valve in the inlet line to minimize the escape of water into the whirl pit.

Experiments with thermocouples connected to fairly heavy blocks of metal showed that the thermocouple readings depended on the temperature of the metal and that sudden application or removal of the induction field did not affect the readings.*

Temperature distributions in a steel disk and in the General Electric Type B turbosupercharger wheel are shown by Fig. 4. The turbine blades of the bladed wheel were closer to the induction coil than was the rest of the wheel. The blade temperatures were much lower than the temperatures of the continuous part of the wheel, suggesting that the blades did not provide the continuous path of sufficient impedance needed for eddy-current heating with 10 kc. The temperature distribution in the blades suggests that they were mainly heated by conduction from the rim.

Direct heating of the blades by using a higher frequency was attempted with a 400-kc vacuum-tube oscillator. Arcing occurred between the closely fitted blade shrouds, resulting in poor heating efficiency. Power needed to raise the blade temperature above 1200° F was estimated at 60 kw.

Size of Induction-heating Machines

The amount of power needed depends upon (1) resistive losses in the transmission line and induction coil, (2) stray eddy-current losses in conducting structures in the fields of the transmission line and coil and, (3) power used in heating the disk. Large temperature gradients developed by rapid heating of the rim require power levels several times those required for holding a constant rim temperature.

The induction-heating circuit includes a large multisection capacitor in parallel with the inductor. This capacitor is used to present an approximately unity power factor to the machine. In addition to the in-phase heating power currents, the connections between the inductor and the capacitor carry large out-of-phase currents and should be as short as possible and water cooled to minimize the resistive losses in these leads. The capacitors were therefore removed from their positions in the cabinets of the induction-heating machines and mounted at the edges of the spin pits.

The capacitance is fairly critical because the power output of the machine is mainly current limited and the addition of out-of-phase current (current not used for heating power) can easily exceed the rating of the machine. The proper capacitance was determined by trial and error and adjusted by bolting copper jumpers on the capacitors. The magnetic properties of the test-wheel change with temperature and this variation changed the inductance, requiring adjustment of the capacitor. Adjustments of the capacitor were especially inconvenient after heating and spinning had started. Large machine size then became a valuable asset because it allowed the test to be continued even though the power factor

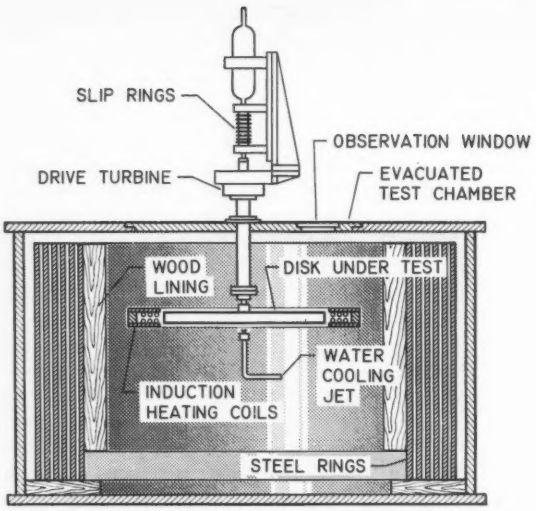


Fig. 5—Spin rig used for small-disk burst tests

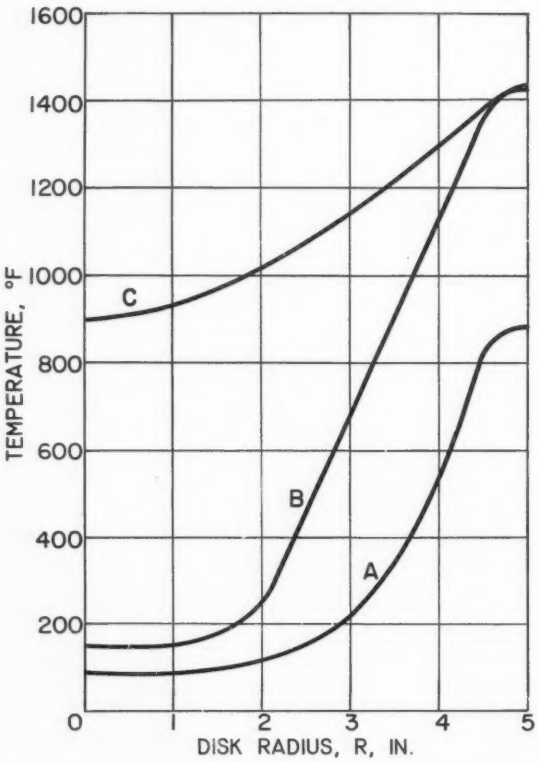


Fig. 6—Temperature distributions of small-disk burst tests. Curve A at low power level; curves A and B obtained with water-jet cooling at center of disk

* *Also see section on "Optical Pyrometers."*

TABLE 4—HEATING CYCLE FOR LARGE-WHEEL TESTS

Power, kw	Time at power, min
5	60 (allowing checks of instrumentation)
10	5
15	5
20	Wheel accelerated to burst with minor downward adjustments of power to maintain rim temperature at about 1170° F

was less than ideal. However, installation of a machine that is much in excess of requirements is undesirable because of cost and because the controls are such that temperatures cannot be as accurately and stably adjusted as when the machine is operated near its rated output.

The rated output of the machine limits the rate of heat input at the rim. The rate of heat input at the rim determines the steepness of the temperature gradient that can be obtained. Adjustment of the rate of heat input simulated the equilibrium temperature distribution of the wheel in an engine. In typical results, the center temperature was 300° F and the rim temperature was 1170° F. The time-heating cycle is given by Table 4.

Minimum power requirements for a variety of test disks and wheels are given by Table 5. Heating to the test temperatures was sometimes accomplished with power levels as much as 50% in excess of the values shown by Table 5. In general, a good choice of size for an induction-heating machine is probably one with a rating that is twice the minimum equilibrium power requirement. This reserve could be smaller if the capacitor could be finely adjusted during spin-pit operation.

Induction-heating Coils

Conditions for the design of induction-heating coils are complex and calculations are only of value for preliminary estimates. A small background of experience can eliminate the preliminary calculations. Subsequent "cut and try" is always needed, particularly when the coil must be optimized for some particular temperature distribution.

Coils for the small-disk tests using the 15- and 30-kw machines were always connected directly to the 220-v output terminals. The larger wheels were heated with the 75-kw machine and the correspondingly higher-inductance coils were directly connected to the 440-v terminals. Matching transformers were never needed between the heating coils and the generator.

The inductor coils were wound from copper tubing. A steady flow of water inside the tubing protected the copper from the resistance heating of the electric current in the tubing and from the radiant heat of the test wheel. The inductor coil inside the spin pit was connected to bus bars on the capacitor by leads consisting of similar water-cooled tubing. Trouble-free connections between coils and leads were made by using tubing for leads with an inside diameter about equal to the outside diameter of the tubing in

TABLE 5—MINIMUM EQUILIBRIUM POWER REQUIREMENTS OF INDUCTION-HEATED SPIN-TEST WHEELS

[Frequency 10 Kc.]

Wheel design	Rim temperature, ° F	Machine output, kw	Machine power rating, kw	Heating-coil arrangement
10-in. diam $^3/_4$ in. thick disk of Inconel-X	1425	4	15	Fig. 5
10-in. diam, $^3/_4$ in. thick, bladed wheel of Inconel-X	1350	7	15	Fig. 2
	1500	13	30	Fig. 2
12-in. diam, $^3/_4$-in. thick, bladed wheel of AMS 5602	1100	6	15	Fig. 2
Full-size welded composite J35 and J47 wheels*	1130	14	75	Figs. 8 and 9
	1350	28	75	Figs. 8 and 9

* Dimensions and materials given in Ref. 8.

the coil. The larger tube was slipped over the smaller for a length of about 2 in. and the two were silver soldered together. Equally good results in connecting tubes of like diameter were obtained by using commercial brass fittings made to aircraft standards. Aluminum-alloy tube fittings failed in service. Perhaps the aluminum was softened by heat, allowing a water leak that facilitated electric arc-over and destruction of part of the coil.

The arrangement of Fig. 5 was used with a parallel-sided 10-in. diam by $^3/_4$-in. thick disk of a low-magnetic-permeability heat-resisting alloy (Inconel X). The coils were water-cooled $^1/_4$-in. OD copper tubing which was coated with Bakelite BC 6035 cement to prevent arcing. Clearances between the test disk and the coil have varied from $^3/_{16}$ to $^1/_2$ in. Rapid heating to 1425° F was obtained with 12.5 kw, and this temperature was maintained with about 4 kw. Some temperature distributions attained are shown by Fig. 6.

The arrangement of Fig. 2 was used with 12-in. diam by $^3/_4$-in. thick steel disks with blades attached to the disk by a conventional "fir-tree" fastening. These disks were heated by a pair of "pancake" coils wound with $^5/_{16}$-in. OD, 0.035-in. wall-thickness tubing and located as shown by Fig. 2. The upper and lower three-turn coils were connected in series. The coils were fastened to Transite insulating blocks. Some coils were used without insulation on the turns and, in some cases, glass sleeving was slipped over the copper tubing to prevent contact of adjacent turns. An equilibrium temperature of 1100° F was obtained at power levels from 6 to 12 kw, depending upon the amount of spin-rig structure near the coils. Structures of low-resistance nonmagnetic materials were superior and $^1/_4$-in. brass plate was used extensively. Water circulating in copper coils (Fig. 2) cooled the test-disk center. The resulting temperature distribution is shown by Fig. 7.

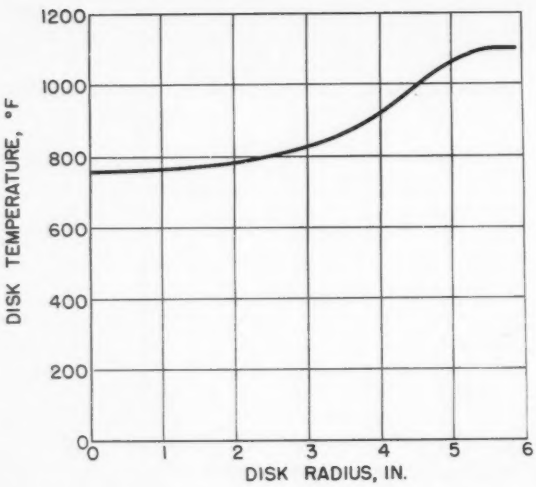


Fig. 7—Radial-temperature distribution in wheel, blade-fastening endurance tests

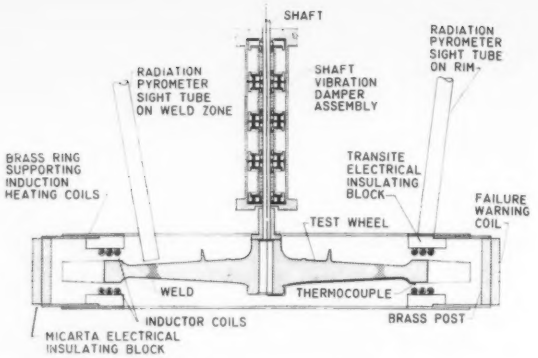


Fig. 8—Vibration damper and heating coil for large-wheel burst tests

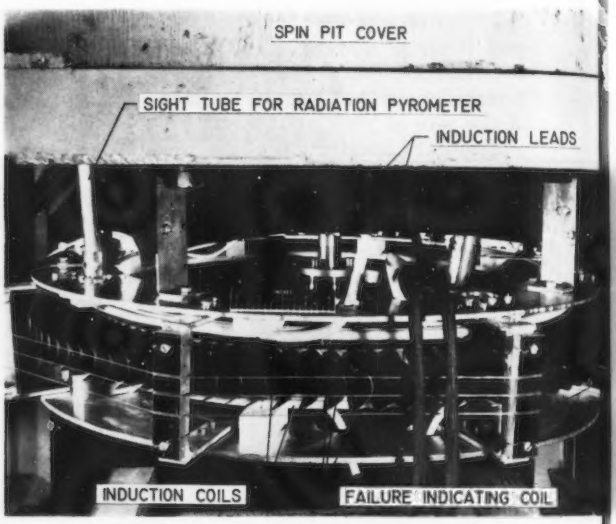


Fig. 9—Induction heating and failure-indicating coils used with large-wheel burst tests

The general arrangement of coils for the large-wheel tests is shown by Figs. 8 and 9. Construction details were similar to the coils of Fig. 2 as just described. Some results are shown by Fig. 10.

Temperature Measuring

Thermocouples

Chromel-Alumel thermocouples were always used. The early tests used thermocouples that were spot welded to the wheels. Thermocouple wires were encased in small-diameter Inconel tubing held down by small stainless-steel straps spot welded to the wheels. Speeds sufficient to stretch the wheels usually destroyed the rim thermocouples by throwing the tubing completely off or by stretching the thermocouple wires so that they looped out beyond the thermocouple and were pulled off the wheel.

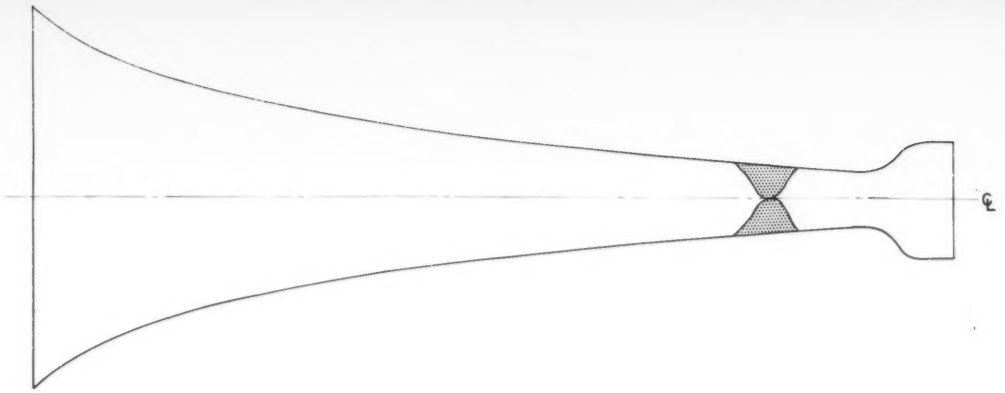
Thermocouple life was greatly improved by using swaged tubes. Thermocouple wires in magnesium-oxide sleeves were inserted in stainless-steel tubing and swaged from a diameter of 0.080 in. to a diameter of 0.062 in. This crushed and resolidified the magnesium oxide so as to tightly bind the wires in the tube. The thermocouple was balled and peened into a small hole in the wheel surface.

A note of caution is in order in reference to the time–temperature spin tests in that great care must be exercised to prevent petroleum lubricating oils from contaminating thermocouple assemblies mounted in the hot zone of the disk. At time and temperature, carbonaceous products formed will introduce some error in the thermocouple readings. To establish the level of error under these conditions, exploratory tests were made on swaged magnesium-oxide insulation and conventional Alundum beaded thermocouple assemblies. These thermocouple assemblies were immersed in petroleum oil and then heated at time and temperature conditions simulating some hot-spin tests. Figure 11 shows characteristics of the swaged magnesium-oxide and Alundum insulations. After 38 and 22 hr, respectively, at 1350° F, the leakage resistance dropped to approximately 3 ohms from a resistance well above a megohm prior to petroleum-oil immersion. This deterioration of the thermocouples can introduce errors of approximately 80 to 100° F as shown in Fig. 11.

When the same exploratory bench test was performed using "U Con" oil (a water-insoluble polyalkylene glycol lubricating oil with unusually high resistance to formation of sludge and carbon), the relatively small leakage resistance drop after 90 hr at 1350° F did not produce an error in temperature that was detectable within the accuracy of the test.

Slip Rings

The thermocouple voltages were transmitted from the rotating wheels to stationary instruments through $^{7}/_{8}$-in. diam slip rings (Fig. 12). Circuits



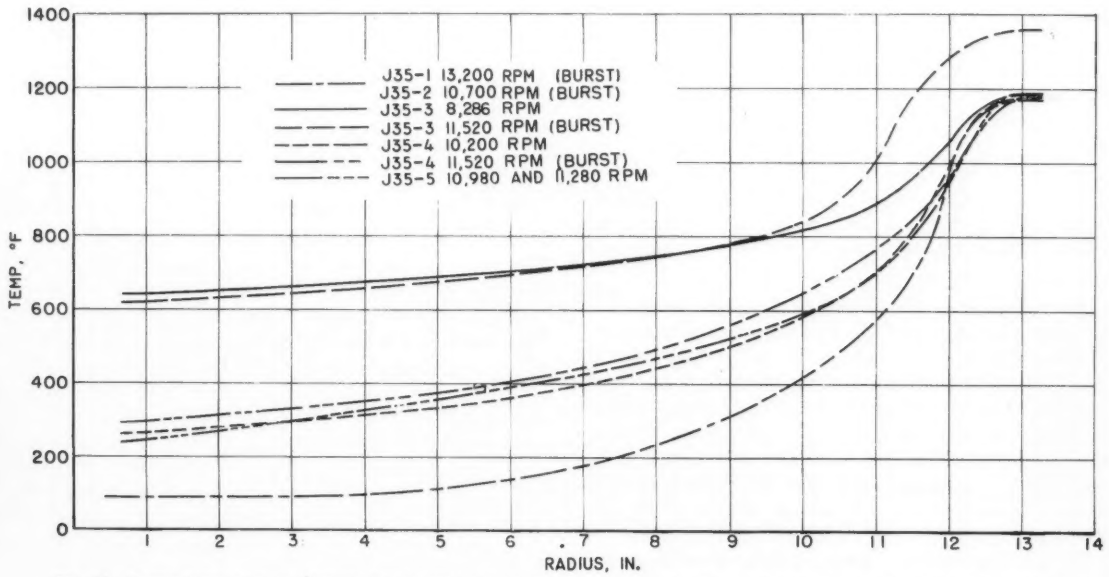


Fig. 10—Some temperature distributions attained during large-wheel tests. Centers of wheels J-35-1 and J-35-2 were cooled by water jets. Dash numbers are spin-test numbers

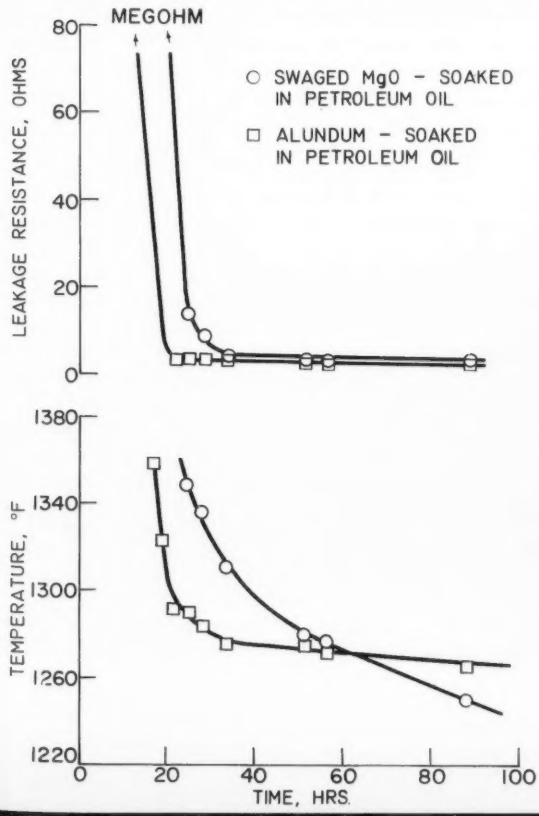


Fig. 11—Drop in leakage resistance and corresponding drop in temperature readings of thermocouple assemblies at 1350° F. Zero time is start of heating. Thermocouples soaked in oil after each resistance reading

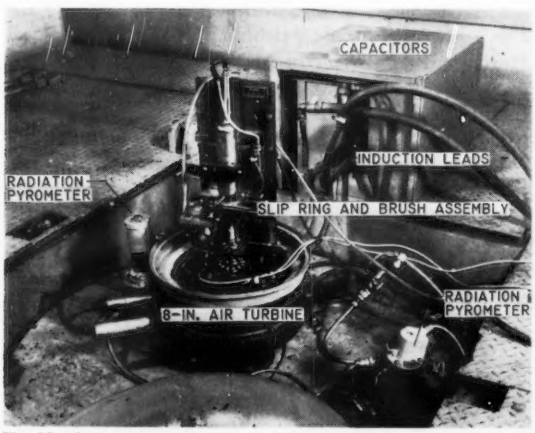


Fig. 12—Capacitors, slip rings and radiation pyrometers used with large-wheel burst tests

were as described in Ref. 12. The tests of Ref. 6 and the early tests of Refs. 7 and 8 were run using copper rings and copper brushes. Troubles with this brush-ring combination led to improvements in operating procedures that will be described. The later two-thirds of the testing of Refs. 7 and 8 was done with silver rings and silver-graphite brushes. The advantages of this combination will also be given.

Construction of the copper rings and brushes was according to Ref. 12. Brushes were caused to contact the rings by the electromagnet only at times when a temperature reading was desired. Copper particles between the rings and hair-like copper turnings strung across the brushes were sometimes observed after the tests of Ref. 6 and the early tests of Ref. 8. Jets of commercial solvents directed at the rings were partially successful in removing the debris during operation. This practice was not followed during the endurance tests of blade fastenings because, in time, the solvents might have damaged the slip-ring insulation.

Improved operating procedures were used with the copper rings in the early blade-fastening endurance tests. A commercial oil-mist lubricator supplied oil mist to a spray bar that directed jets of oil mist at the rings and brushes. The thermocouple voltages were read on a multichannel "Brown" self-balancing strip-chart recorder. The instrument contains an automatic selector switch that continuously transfers the measuring circuit from one thermocouple to the next. The chart drive switch was used manually to interrupt the selector switch and to hold the measuring circuit on a particular thermocouple for the one or several seconds required for a steady reading. This time may have depended on the brush pressure and the thickness or tenacity of an accumulated oil film. (Each brush was held against its ring by a leaf spring previously adjusted to a force of 6 oz.) Apparently, the oil provided boundary lubrication that reduced the brush wear but allowed the voltage to be sensed accurately by the null-method potentiometer. This objective was furthered by using the instrument without "upscale" or "downscale burnout." The circuit was interrupted after the multichannel selector switch by a double-pole double-throw switch so that a thermocouple could be connected either to the measuring circuit or to an ohmmeter. Periodic readings with the ohmmeter were useful in diagnosing slip ring and thermocouple troubles. Slip-ring wear was associated with unsteady ohmmeter readings, while thermocouple short and open circuits were associated with decreased or increased resistance readings.

When the early operating procedures of the large-wheel burst tests were used, the copper rings and brushes regularly produced random deviations of readings as high as 20° F and occasional deviations as high as 50° F from a faired trend line. In the case of the blade-fastening endurance tests, the improved operating procedures were estimated to involve typical errors of 10° F and occasional errors of 25° F.

Greatly improved results were obtained by using silver rings and silver-graphite brushes with the best operating procedures that had been developed for the copper rings and brushes. The silver rings were made from coin silver alloy. The brushes were $^1/_8$-in. in diam and were 60% silver and 40% graphite by weight. Six thermocouples equally spaced around the wheel of Ref. 7 and all located at the same radius showed a total variation of 10° F. This variation may have been due to slight variations in the installation of the thermocouples or it may have been due to an actual variation of disk temperature. Special tests with silver rings and silver-graphite brushes at 18,000 rpm showed common errors of 2° F and occasional errors as high as 5° F.

Optical Pyrometers

Some of the short-time small-disk burst tests of Ref. 6 were run with rim temperatures above 1400° F. An optical pyrometer was used to supplement thermocouple readings. Readings obtained during the spin tests and during special calibration tests with resistance heaters duplicated thermocouple readings within the accuracy of the pyrometer (±12° F).* The optical pyrometer was approximately 9 ft above and 6 ft horizontally away from the glass window of the evacuated test chamber. A cardboard tube connected the observation window with the optical pyrometer so as to prevent extraneous light from interfering with the view of the dull-red rim of the test disk.

Radiation Pyrometers

Radiation pyrometers were used with the large-wheel tests as shown by Figs. 8 and 12. Readings from the pyrometers gave the progress of the heating during time periods between the thermocouple readings. Near the completion of tests at high strains, the outer thermocouples were often torn loose from the wheel. The radiation-pyrometer readings then gave evidence that the wheel temperature had remained constant during the last few minutes of the test.

Because the voltage generated by a radiation pyrometer varies approximately as the fourth power of the disk temperature, good sensitivity at the operating temperature is to be obtained by selecting a pyrometer with maximum rating close to the operating temperature. Good sensitivity was desired so that the output voltage could be accurately sensed by a self-balancing recording potentiometer.

One method of getting a good signal from a radiation pyrometer is to mount it in close proximity to the wheel. This also confines the field of view of the pyrometer to the point on the wheel where temperature information is desired. However, such a

** The agreement with the optical-pyrometer readings gave further support to the hypothesis that induction heating does not interfere with thermocouple readings.*

location could not be used because excessive damage to the pyrometers would follow the wheel bursts. Mounting the radiation pyrometer above the cover plate as shown by Fig. 12 resulted in only a few occasions when pyrometers were damaged by wheel-burst shocks transmitted through the spin-pit structure.

The region of high temperature in a small test wheel with a steep temperature gradient is quite small with respect to the target diameter of most radiation pyrometers. Mounting the pyrometer on top of the spin-pit cover plate puts a distance between the instrument and the wheel that aggravates the sensitivity problem. The radiation-pyrometer optical system should be carefully selected to have an optimum target diameter at the necessary distance between the test wheel and the radiation pyrometer. In some cases, sensitivity in the range of 1100° F was improved by the use of radiation pyrometers having calcium-fluoride lenses.

Figure 8 shows a tube between the wheel rim and the radiation pyrometer. During the long-time endurance tests of blade fastenings, air was admitted at the upper end of such a tube and allowed to flow downward to the disk. This purging was done to provide a line of sight for the pyrometers that would be clear of the oil mist and smoke that occasionally rose from the wheel. The air flow was adjusted to raise the pit pressure from 3.0 to 10.0 mm of mercury absolute.

As supplied by the manufacturer, the cold junctions of the radiation pyrometers were designed to be temperature compensated in air. As used on the spin pits, the lens side of the pyrometer was exposed to the pit vacuum and the rear face was exposed to the atmosphere. The pressure inside the pyrometer was unknown. A steady calibration was achieved by mounting the pyrometers on water-cooled bases so that the cold-junction temperature would remain constant.

Unattended Operation

The blade-fastening endurance tests used the spin pits as "centrifugal stress-rupture machines." Individual wheel tests (Ref. 7) lasted as long as 1000 hr. Unattended "round-the-clock" operation was desired for such tests. It was achieved through the use of automatic control systems that maintained constant experimental conditions and through the use of an automatic safety-interlock system that protected all the equipment against failure of any single item.

Use of Automatic Controls

Each of the two experimental conditions (speed and temperature) were sensed by three independently functioning instrumentation systems, namely, (1) automatic controlling, (2) manual precision calibration, and (3) automatic safety monitoring. The automatic controls were used to maintain constant speed and temperature during unattended 8-hr

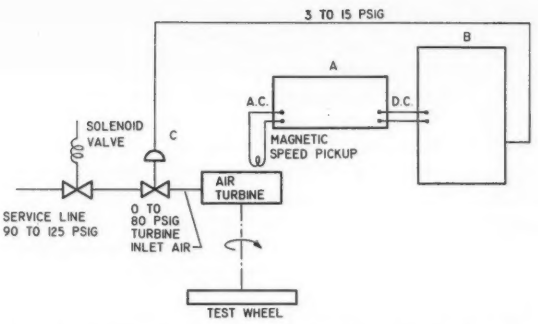


Fig. 13—Automatic speed-control system used with blade-fastening endurance tests

A—"Electronic Frequency Meter," Hewlett Packard Model 500A
B—"Air-O-Line Controller," Brown Model 152 P13 P
C—One-in. pilot-operated pressure regulator with diaphragm loading top, Leslie class LTA-3

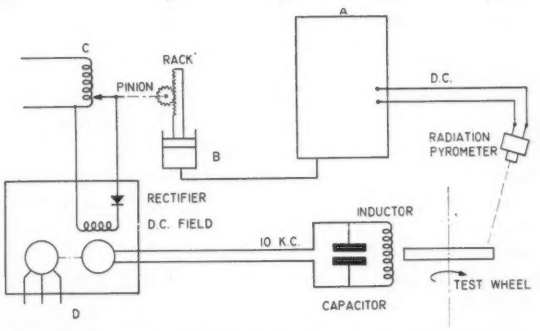


Fig. 14—Pneumatic automatic temperature-control system used with 15 KW induction-heating machine for blade-fastening endurance tests

A—Potentiometer and "Air-O-Line Controller", Brown Model Y152 P13 P
B—"Domotor" actuator, Annin Co., Size A, 25 sq in
C—"Variac" adjustable auto transformer, General Radio Type V5MT83
D—"Tocco" induction-heating machine, Ohio Crankshaft, Type 15STMG10B

periods. At the end of each period, the speed and temperature were manually observed with precision equipment and minor adjustments were made to the set points of the automatic controls. The automatic safety monitors were limit devices that were connected to the safety-interlock system.

Automatic Speed Control

A speed-control system especially designed and built for spin pit use is described in Ref. 13. NASA used standard commercial products arranged according to Fig. 13. Constant-speed operation was achieved by applying the d-c output voltage from the Hewlett Packard frequency meter to a Brown Instrument Co. recording potentiometer and Air-O-Line pneumatic controller. The output pressure of the controller is controlled from 3 to 15 psig. It was applied to a Leslie Co. 1 in. pilot-operated pressure regulator fitted with a diaphragm loading top so that the 3 to 15 psi instrument output pressure would produce regulated pressures from 0 to 80

psig at the input of the 8-in. air turbine. The turbine air supply was nominally 125 psig taken from the general-service air line. Depending on other users, the supply pressure varied as much as 30 to 40 psi. The Leslie pressure regulator prevented these fluctuations from entering the control loop. Manual precision calibration consisted of speed checks with a digital-reading pulses-per-unit-time meter. Typical operating speeds were in the range of 13,000 to 21,000 rpm and speed was maintained within ±100 rpm or ±0.5% of maximum.

Automatic Temperature Control

Temperature was sensed by a radiation pyrometer aimed at the wheel rim. Voltage from the pyrometer was applied to a recording potentiometer that also operated a controller in the generator field circuit of the induction unit to maintain constant temperature. Two spin pits and associated heating machines were used. A 15-kw machine was controlled by a pneumatic system and a 30-kw machine was controlled by an electrical system.

The pneumatic system (Fig. 14) applied the voltage of the radiation pyrometer to a Brown potentiometer with coupled "Air-O-Line" controller. The controller varied the air pressure to an Annin "Domotor." The "Domotor" was fitted with a gear rack that meshed with a pinion mounted on a General Radio "Variac." The "Variac" was located in the a-c side of the field supply of the 15-kw induction machine.

The electrical system (Fig. 15) applied the voltage of the radiation pyrometer to a Leeds and Northrup "Speedomax" recorder and model 10762 control. This control operated a motor on a rheostat connected to a voltage regulator (Clark Controller Co.). The voltage regulator ordinarily maintained a constant voltage output from the induction machine except when a temperature correction was called for by the Leeds and Northrup controller.

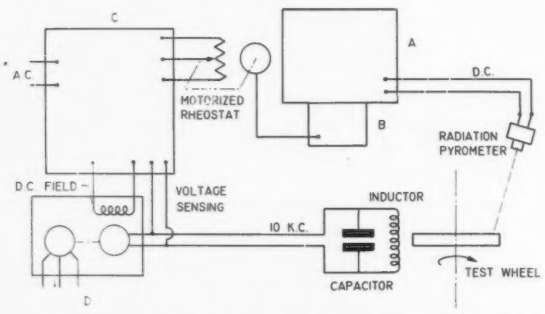


Fig. 15—Electrical automatic temperature-control system used with 30 KW induction-heating machine for blade-fastening endurance tests

A—"Speedomax Type G" potentiometer, Leeds and Northrup Model 60668-C2-436 H
B—"Electrical Control Unit", Leeds and Northrup Catalog No. 10762
C—Rectifier and adjustable voltage regulator, Clark Controller, S.O. B99373-A
D—"Tocco" induction-heating machine, Ohio Crankshaft, Type 2MG 302-1

TABLE 6—OPERATION OF SAFETY INTERLOCK SYSTEM

Condition	Means of sensing
Air-turbine overspeed	Magnetic speed pickup connected to frequency meter. D-c output connected to suitable relay
High or low disk temperature	Stationary thermocouple 1/4 in. above wheel rim connected to suitable relay set to operate at limit points above and below normal output of thermocouple
Air-turbine bearing temperature	Thermocouple touching outer race connected to suitable relay
Air-turbine bearing or suspension-system friction	Pressure switches on turbine inlet air responding to abnormally high or low pressures as called for by speed-control system
Turbine and damper lubricating-oil pressure	Pressure switches
Lubricating-oil supply	Float switch in oil reservoir
Cooling water to induction coils and capacitor	Water-flow switches in outlet lines
Oil pump, vacuum pump or induction-machine overload	Relay connected between motor and its circuit breaker
Suspension-shaft failure	Limit switch close under test wheel
Wheel failure	Helical coil like Fig. 9 connected in 24v d-c circuit to throw relay for open or grounded coil

The electrical system could react to disturbances in the supply voltage of the induction-machine motor before these disturbances could affect the wheel temperature. With the pneumatic system, a reduction of input voltage to the induction-machine motor would first have to reduce the wheel temperature before corrective action would begin. Manual precision calibration consisted of observing the disk temperature by means of the disk-mounted thermocouples, slip rings and the recording self-balancing potentiometer. Such measurements showed that neither control system produced fluctuations in excess of 2° F, which was the limit of resolution of the thermocouple and slip-ring system. Eight-hour periodic checks for drift required adjustments of less than 5° F.

Automatic Protection of Equipment and Test Wheel

The malfunction of any part of the spin-test system could operate the wheel at incorrect test conditions or could result in expensive damage to other parts of the system. An automatic protective system was needed for the 8-hr periods of unattended operation.

The protective system was provided by a safety-interlock system of electrical relays connected to the speed and temperature safety monitors and to all other critical items (Table 6). Because all electric motors were operated by relays and because a spring-loaded solenoid valve (Fig. 13) was located in the

air-turbine supply line, the entire operation was shut down by any signal that actuated any part of the safety system. Any shutdown of the system also stopped an elapsed-time meter, thus providing a record of wheel time at test conditions.

An additional set of relays was connected to a set of indicating lamps and acted as a memory device. Activation of any safety device closed a relay in the memory device and lighted an indicating lamp labelled to correspond to the particular safety device. A shutdown during unattended operation caused, for example, by the float switch in the oil reservoir would light the "low oil level" lamp and thus save the time that might be lost using intuitive trouble shooting.

Summary of Results

Hot-spin test methods were developed that were adequate for several disk-strength investigations. Features that may have been unique were, (1) the very extensive use of suspension-shaft vibration damping, (2) the use of radiation pyrometers in combination with induction-heating machines for automatically maintaining constant-equilibrium temperature distributions, and (3) the use of an indicating-lamp memory device with a safety system so as to accelerate the diagnosis of shutdowns that occurred during unattended operation.

In particular:

1. Parts subject to friction such as turbine bearings, vibration-damper parts and oil seals performed satisfactorily for tests lasting up to 1000 hr.

2. An air turbine was modified for the successful spinning of a 4800-lb rotor at a speed of 4320 rpm.

3. A speed-control system maintained drift at less than ± 100 rpm during 8-hr periods. Tests were conducted in the speed range of 13,000 to 21,000 rpm.

4. A shaft vibration-damper system was developed that, in a typical instance, tolerated a shift of mass center of 0.037 in. (equivalent to a calculated force of 8 tons for no change of mass center).

5. The combination of coin-silver rings and silver-graphite brushes was found to be especially useful for transferring voltages from disk-mounted Chromel-Alumel thermocouples to stationary instruments consisting of self-balancing recording potentiometers. Durability was enhanced by lubricating the rings with a light-oil mist. Special tests under these conditions showed that the slip rings introduced error of less than $5°$ F.

6. An optical pyrometer was found to be suitable for observing a rim temperature of $1425°$ F with an error less than $\pm 12°$ F.

7. The use of induction heating at the rim and radiation cooling at the center was satisfactory for representing the equilibrium temperature distributions of aircraft gas-turbine disks.

8. Radiation pyrometers were suitable for automatic control of induction-heating machines to maintain test disk-rim temperatures constant with drift less than $\pm 5°$ F during 8-hr periods.

9. A safety interlock system was developed so that spin-pit facilities could be operated unattended. The safety-interlock system protected all the equipment against the failure of any single item. An associated relay and lamp system indicated the reason for shutdown.

Acknowledgments

The authors are indebted to personnel who contributed greatly to the development of the hot-spin test techniques as follows:

The 8-in. air turbine was redesigned for the extra-heavy-load slow-speed test by Edward Satmary. Sol Young (when with NACA) and Chester Tudburry (when with Ohio Crankshaft) conducted the preliminary induction-heating tests. Paul Wilterdink (now with Phillips Petroleum) coordinated much of the design and selection of the hot-spin test facilities. Arthur Bardsley (when with NACA) and Sam Calamia developed the automatic-speed-control system. Austin Herr contributed advice and suggestions with respect to the usage of almost all the instruments. John P. Kelley designed the safety-interlock and memory system. Some of the design features, and the efficient and reliable operation of all the equipment were the result of the work of Peter Moran, Thomas Glenn, John Merriner and Royal Boyd.

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Applications of Photoelastic Strain Gages

Several applications of two types of photoelastic gages for strain measurements on metallic and nonmetallic structural members are demonstrated and their features discussed

by Joseph Schwaighofer

Joseph Schwaighofer was associated with Department of Engineering Mechanics, The Pennsylvania State University, University Park, Pa., at time that paper was prepared.

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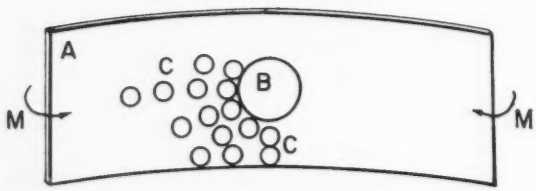
SUMMARY—This paper deals with various applications of newly developed photoelastic gages for strain measurements on metallic and nonmetallic structural members. Simplicity of application and direct indication of the magnitude and the directions of the principal strains in biaxial-stress fields are some of the merits of photoelastic strain gages.

Introduction

New tools for measuring strains on the surface of stressed structures and machine parts have been developed recently by G. U. Oppel.[1] These new measuring devices utilize well-established principles



a

b

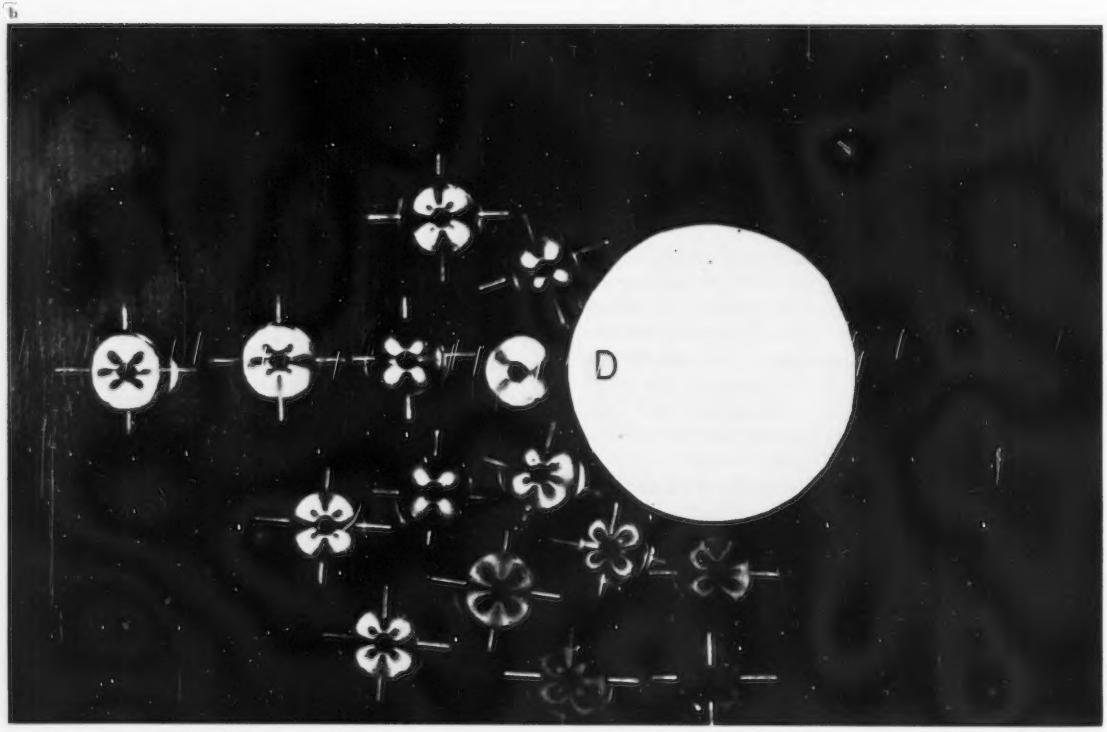


Fig. 1—Biaxial photoelastic strain gages attached to an aluminum plate and subjected to bending
A = Aluminum plate
B = Circular hole
C = Biaxial photoelastic strain gages
D = Biaxial strain gage in region of low stress

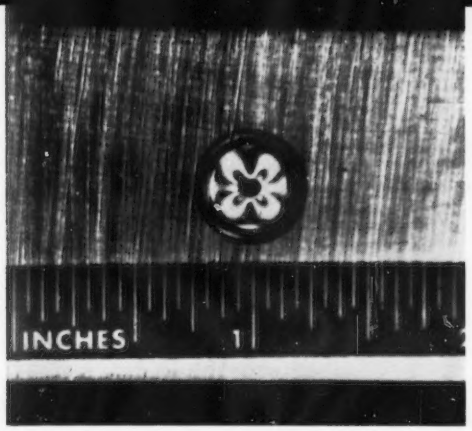


Fig. 2—Small biaxial photoelastic strain gage (outer diameter is 0.30 in) subjected to bending stress

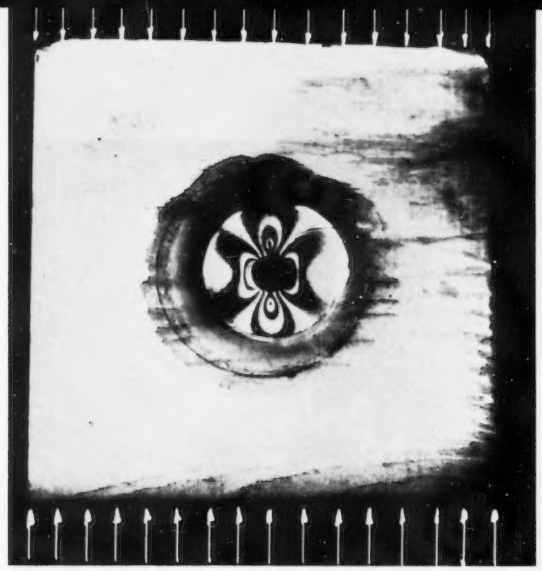


Fig. 3—Photoelastic gage attached to wooden block and loaded perpendicular to the fiber

of photoelasticity and are, therefore, designated as "photoelastic strain gages." Two types of photoelastic strain gages have been developed for the determination of the directions and magnitudes of the principal strains.

(a) The biaxial photoelastic strain gage (also called a compass gage) which is primarily used for determining the principal-strain (stress) directions. It consists of a thin circular disk of polished photoelastic material and has a small hole at its center. The disk rim is glued to the surface of the structural part, and the rim is therefore subjected to the same strain which the structural part undergoes in this region. Depending upon the magnitude and the ratio of the principal strains which are imposed upon the gage plate, characteristic fringe patterns appear in the photoelastic compass gage. The directions of the principal strains are given by the axes of symmetry of this fringe pattern. Details of the gage and characteristic fringe patterns are described in Refs. 1, 2 and 3.

(b) The uniaxial photoelastic strain gage, used for measuring the magnitude of the principal strains, consists of a small rectangular plate of photoelastic material into which parallel interference lines have been "frozen-in."[4] The gage plate is provided with one reflecting surface. Only the ends of the gage plate are glued to the member to be tested. The mirrored surface of the gage is protected by a plastic tape which, at the same time, permits free motion of the central portion of the gage. Upon application of stress, the frozen-in interference fringes move with respect to their original position. The amount of displacement of an interference line (with respect to its initial position) is linearly proportional to the magnitude of the strain produced in the part under consideration.

Applications

In the following, several applications of both types of photoelastic strain gages are demonstrated and their features discussed. In Fig. 1, a rectangular aluminum plate (A) is shown which has a hole (B) at its center. It is subjected to bending moments at the ends (see Fig. 1a). In order to determine the principal-stress directions in the vicinity of the hole, photoelastic compass gages (C) were glued to the surface of the plate. Upon application of the bending moments (M), a characteristic fringe pattern appeared in each of the strain gages. The principal-stress directions are given by two axes of symmetry which are emphasized on the photograph by white lines. Due to the relatively high stress gradient around the hole, it was necessary to use small photoelastic gages. The radius of the Araldite gages which were used here is 0.25 in. A distorted fringe pattern (i.e.: a pattern which does not have two or more perpendicular axes of symmetry) in a photoelastic compass gage indicates that the selected gage size is too large for accurate determination of the principal-stress directions, and that a gage with smaller diameter should be used. In each particular application, the fringe pattern of the photoelastic strain gage indicates whether or not the size of the gage is sufficiently small to consider the area occupied by the gage as a biaxial-stress field with constant ratio of the principal stresses. The gage (D) in Fig. 1b is in a region of very low stress and displays, therefore, hardly any fringe pattern. The photograph in Fig. 2 was taken to demonstrate that photoelastic strain gages with an outer radius of 0.15 in. can successfully be used. This fact is of importance in regions of high stress gradients and in and near fillets.

The evaluation of strain-rosette readings for the purpose of determining principal-strain directions becomes quite involved (see Ref. 5) if the specimen is made of a nonhomogeneous, anisotropic material. This is true, for example, in the case of wood. Three applications of photoelastic strain gages to wood are given in Figs. 3, 4 and 5. An approximately square block of wood (3.5 x 3.1 x 1.4 in.) was successively subjected to a uniform compressive stress first perpendicular to the fiber of the wood (Fig. 3), then

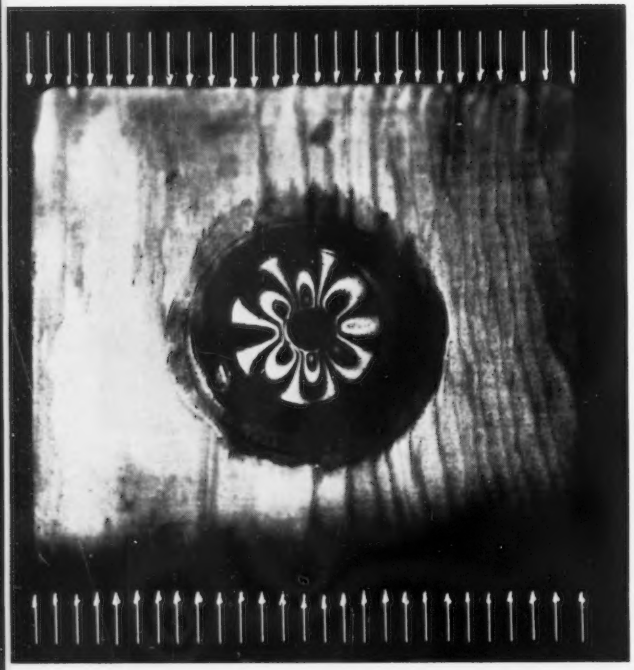


Fig. 4—Photoelastic gage attached to wooden block and loaded in direction of the fiber

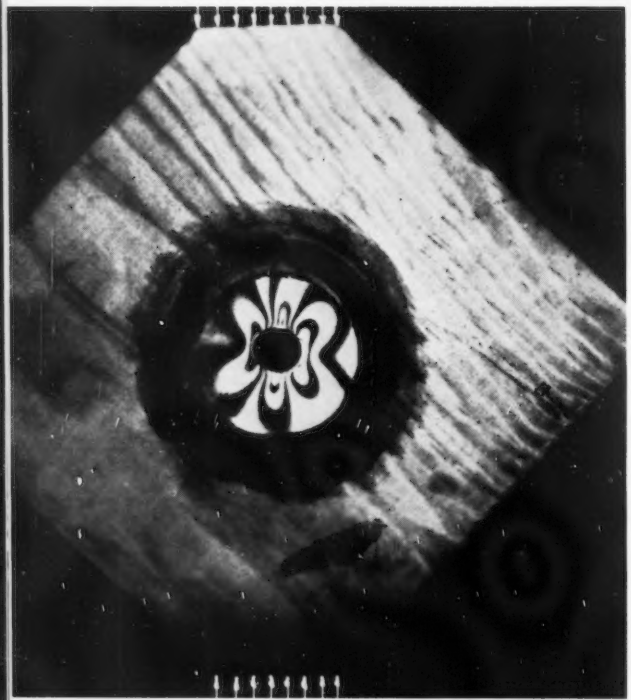


Fig. 5—Photoelastic gage attached to wooden block and loaded at 45 deg with respect to the fiber

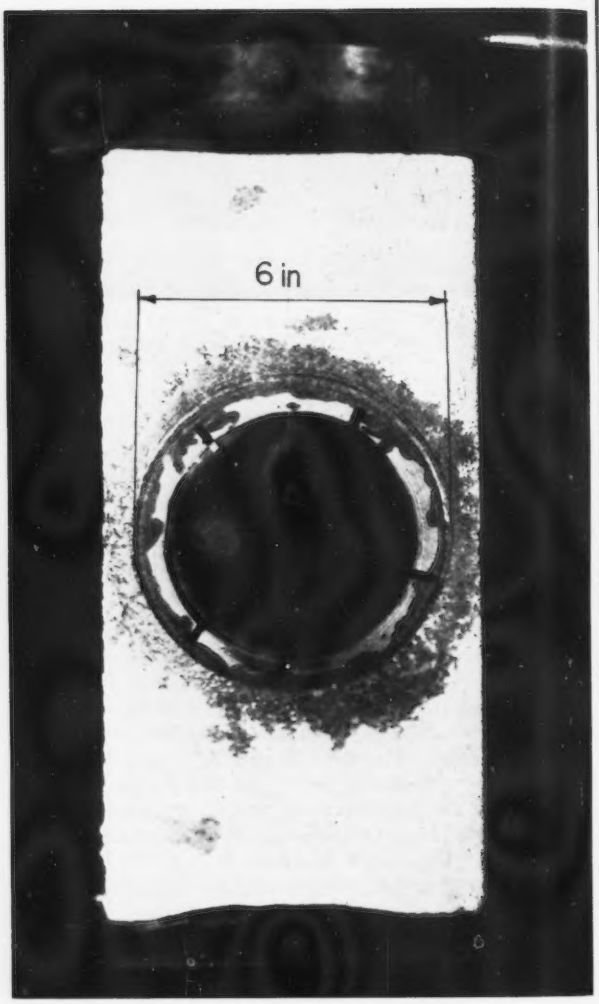


Fig. 6—Biaxial photoelastic gage glued to a block of lightweight concrete and tested in compression

in direction of the fiber (Fig. 4) and finally at an angle of about 45 deg with respect to the fiber (Fig. 5). It is of interest to compare the loads necessary to produce the fringe patterns in Figs. 3 and 4 which display about the same fringe order. The testing machine exerted a total load of 1420 lb when the photograph in Fig. 3 was taken, whereas a total of 15,500 lb was required to produce the fringe pattern in Fig. 4. The fringe pattern in Fig. 5 resulted from a total external load of 3000 lb.

The outer diameter of the strain gages which were used in the three applications just described was 1.5 in. and their thickness was 0.1 in. An epoxy plastic cast from Araldite resin 6020 with hardener 901 served as gage material. The room-temperature-setting Araldite resin 502 with the liquid Araldite hardener 951 was used to attach the gages to the wood.

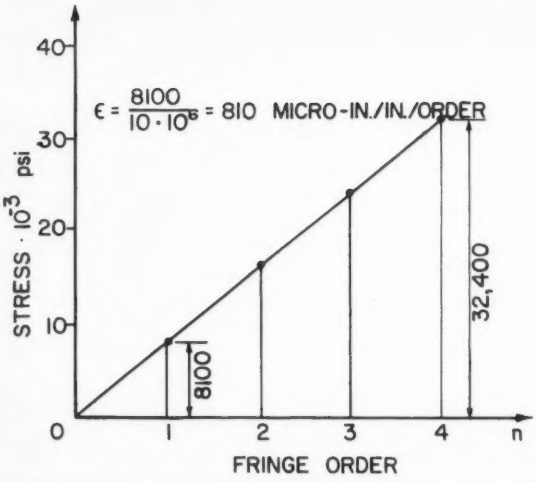


Fig. 7—Stress versus fringe order diagram for a uniaxial photoelastic strain gage attached to a high-strength aluminum bar in tension

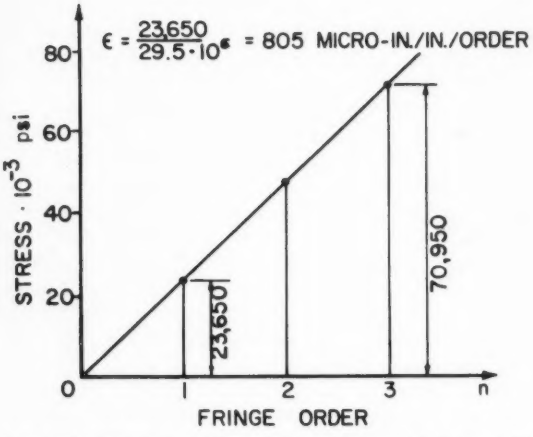


Fig. 8—Stress versus fringe order diagram for a uniaxial photoelastic strain gage attached to a steel bar in tension

Concrete and reinforced-concrete structures present another vast field in which photoelastic strain gages can be used. Since nonhomogeneity is one of the basic qualities of concrete, a decision must be made with regard to the gage length or area over which the strain should be measured, in order to obtain either the localized strain or a "representative" average value over a large area. Both can be achieved by aid of photoelastic strain gages. In Fig. 6, a lightweight concrete block is shown to which a photoelastic compass gage is attached. The block is subjected to a uniform compressive stress along its smaller sides. The gage is 0.5 in. thick and has an outer diameter of 6 in. The gage material was an Araldite plastic, the glue the same as previously described.

Uniaxial photoelastic strain gages are used for determination of the magnitude of strains. They are attached to the specimen along the lines of principal-strain directions, which are clearly indicated by the fringe pattern of a biaxial photoelastic strain gage, previously described. The basic feature of uniaxial strain gages is that strain measurements can be obtained in case of static loading simply by counting the fringe orders, and fractions thereof, which pass an arbitrarily picked location on the gage during the course of loading. The conversion of the counted fringe number into strain is achieved by multiplying the number of fringe orders (and fractions) by the so-called gage factor. The gage factor represents the strain (measured for example in microinches per inch) which is required to shift one frozen-in fringe to the position the neighboring fringe held prior loading. The gage factor depends on the elastic and photoelastic properties of the gage material and is also a function of the geometry of the gage plate and the wave length of the light source used. Photoelastic gages which have the same geometry, i.e., the same thickness and length, and which are made of the same material, have therefore the same gage constant when observed with the same light source. The gage factor can be obtained most readily by means of a calibration test: a photoelastic gage is glued to a tension bar of known cross-sectional area and known modulus of elasticity and subjected to uniform tensile stress. The motion of the interference lines is observed with respect to their zero position. The stresses which introduce shifts in the interference bands of one or more fringe orders are recorded. Figure 7 represents a plot of stress versus fringe order for a uniaxial strain gage (1.25 in. long and 0.1 in. thick) glued to a high-strength aluminum bar. Inspection of this diagram reveals that one fringe order corresponds to a stress of 8100 psi. This is equivalent to a strain in the bar of 810 microinches per in., if the modulus of elasticity of the bar is 10 x 10^6 psi. Figure 8 is a representative stress–fringe order diagram for steel obtained in a manner similar to the one described above. The resulting gage factor was 805 microinches per in. per fringe. With this standard type of gage and the glue employed, a gage factor of 807 $\pm$ 4 microinches per in. was obtained as a result of a large number of calibration tests. A sodium-vapor lamp was used in carrying out these tests (λ = 5890 A).

Uniaxial photoelastic strain gages can successfully be employed for strain measurements on metallic and nonmetallic structural parts. In cases of materials which follow Hooke's law, the strain readings can readily be interpreted in terms of stresses as long as the proportionality limit of the material is not exceeded. For materials such as wood and concrete, only the strains can be obtained directly. In Fig. 9, the linear relationship between the stress in the bar and the strain as indicated by a uniaxial photoelastic strain gage is demonstrated in

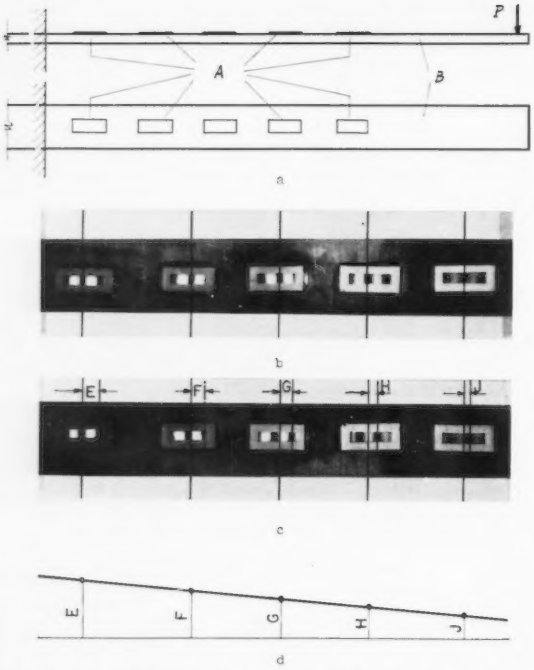
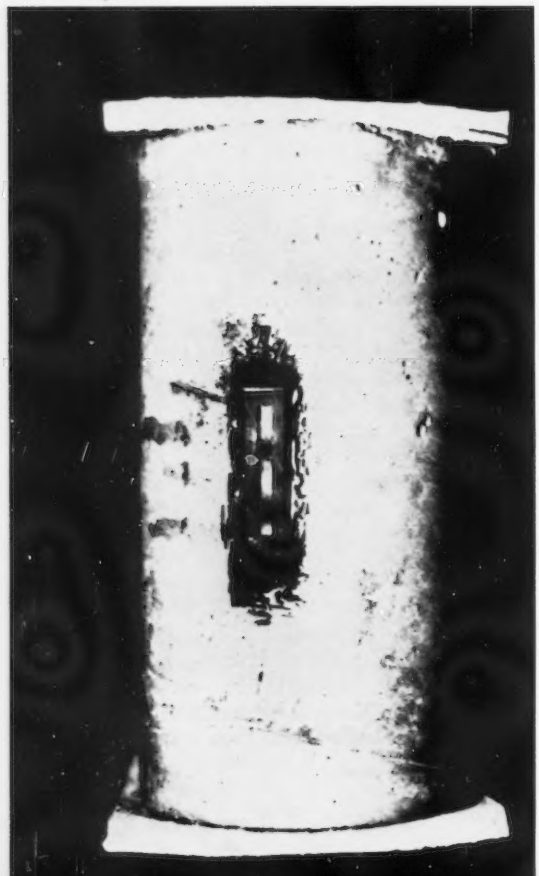


Fig. 9—Demonstration of linearity between stress in an aluminum bar and strain measured by aid of photoelastic strain gages
A—Photoelastic strain gages
B—Aluminum bar
P—Externally applied load

Fig. 10—Uniaxial photoelastic strain gage attached to a concrete cylinder



the following manner: an aluminum bar (B) having a rectangular cross section (nominal dimensions 0.25 x 1.50 in.) is rigidly fixed at one end and subjected to a concentrated load P at the other end of the bar (see Fig. 9a).

The magnitude of the load was selected so as to shift the interference band of the most highly stressed gage approximately into the position the neighboring fringe occupied prior to load application (this means a strain corresponding to about one fringe order was introduced). The gages closer to the applied load show smaller displacements of their fringes. Figure 9a shows the test arrangement while Fig. 9b is a photograph of the fringe pattern of the unstrained five gages (A) which were glued to the top of the bar (B). The shift of the fringe band which took place in each gage due to the application of the load P is labelled in Fig. 9c by the letters, E, F, G, H and J. Figure 9d is a plot of the magnitude of the shift versus the distance of the center of the gage with respect to the applied load. As expected, the test resulted in a straight-line relationship between the stress in the bar and the corresponding strain as measured by the photoelastic strain gage. A modification of the uniaxial strain gage was necessary when it was used to measure strains on a standard test cylinder of concrete (see Fig. 10). In order to secure average-strain values, the gage length was increased to 3.5 in.

Also, the thickness of the gage was increased to 0.5 in. The other features of the gage, such as the sprayed-on mirror and the mirror protecting plastic tape, remained unchanged. In order to attach the gage, the concrete was cleaned and roughened with a steel brush. A thin layer of Araldite glue was applied and 24 hr were allowed for drying of the glue. Now the surface of this layer was roughened and the photoelastic gage was attached to the concrete by aid of the same Araldite glue. Two or three days elapsed between gluing of the gage and its use to insure a strong bond between gage and concrete. In all cases in which photoelastic strain gages were removed from the concrete blocks, the concrete rather than the bond between gage and concrete was damaged.

Acknowledgments

The work described in this paper was carried out in the Department of Engineering Mechanics of the Pennsylvania State University. The writer wishes to express his indebtedness to G. U. Oppel for valuable advice and numerous suggestions.

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Soil-motion Records for Short Exciter-detector Distances

Analysis of soil-motion records due to periodic exciter forces is restricted to exciter-pickup distances ranging from 10 to 200 ft

by R. K. Bernhard

SYNOPSIS—Soil-motion records resulting from studies on "soil dynamics" are analyzed. The investigation is restricted to exciter-pickup distances ranging from 10 to 200 ft (microseismics). Periodic and nonperiodic exciter forces are discussed. Surface displacements in the vertical and longitudinal direction (plane trajectories) and combined with the transverse direction (triaxial motions) have been analyzed.

Introduction

The main purpose of this investigation is an analysis of soil-motion records due to periodic exciter forces.

A detailed knowledge of wave patterns due to vibratory loads might be helpful for studies in connection with discrimination between blasts (nuclear subsurface explosions) and earthquakes.

Impetus leading to this study emanated from experiments[1] on the efficiency of vibratory compaction near resonance frequencies (resonance tamping[2]) of the exciter-soil-mass system.[3–5]

A mechanical vibration exciter oscillator[6] was used which generated a sinusoidal vertical force vector containing no further harmonics or horizontal components. The conditions governing this important feature have been pointed out by J. J. Slade, Jr.[7] and were carefully checked on a vibration table.[8]

Let the frequency of this force vector be referred to as the first harmonic (fundamental, n_f) and hence any periodic wave with half this frequency as the first subharmonic (n_s).

A unidirectional seismometer[9] was located on top of the oscillator. The output of this seismometer yielded the vertical displacement of the oscillator. A typical vertical displacement vs. time (V/t) diagram, traced by a galvanometer oscillograph (G.O.), is shown in Fig. 1.

Three significant characteristics of this trace are noticeable: the exciter frequency, $n_e = n_f = 30$ cps; harmonics; and a rounding-off at every second downward stroke of the force vector.

These three characteristics could be observed whenever the dynamic load (upward force maximum, F) approached the static preload, W which included the weight of the oscillator.

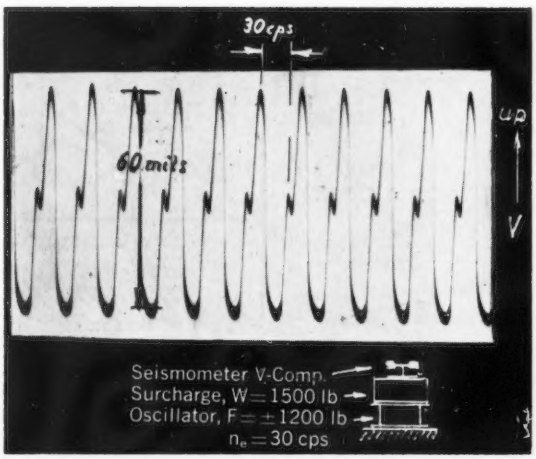

Fig. 1—Displacement of exciter. V/t-record, G.O. W/F = 1.25

The record seems to indicate that the compaction effort of the oscillator became less effective at every second downward stroke; however this does not necessarily imply that the oscillator base lost contact with the soil.

The nonlinearity at every second downward stroke may be due to an increase in spring characteristic of the soil near its maximum compression range.

The above-mentioned abnormalities justify further studies, particularly a synthesis of sinusoidal waves with and without harmonics.

Since investigations of nonperiodic waves have been described fully in the literature[10–12] mostly in connection with earthquake phenomena and refraction shooting (seismic subsurface exploration), they will be discussed briefly for the sake of comparison only.

Experimental Setup

The available instrumentation, measuring technique, soil composition and stratification are similar to those discussed in detail in previous reports.[1, 5, 8]

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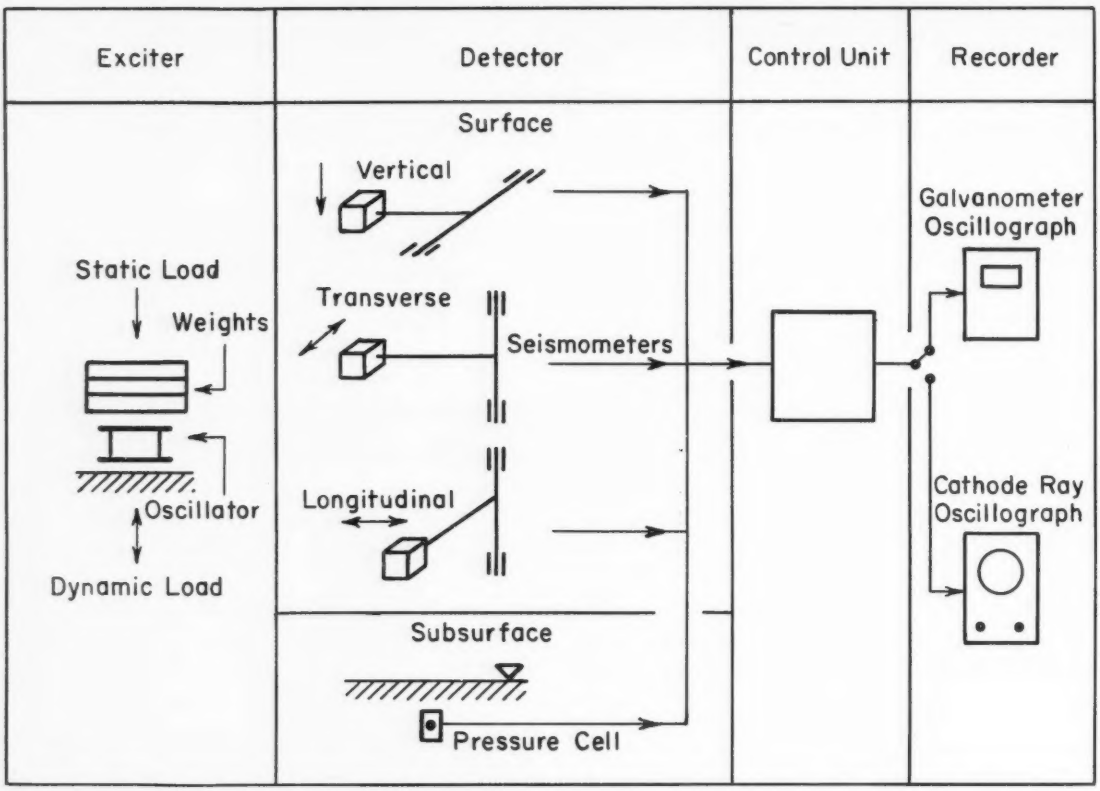


Fig. 2—Experimental setup. Block diagram

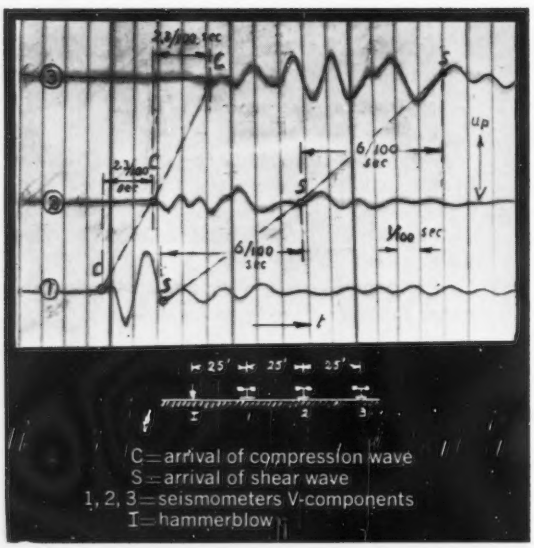


Fig. 3—Surface displacement due to non-periodic force excitation. V/t-records, G.O.

Figure 2 shows the experimental setup. The following types of exciter, detector and recorder units were used:

Exciters: (1) Hammerblows to produce impact forces in the vertical direction (V component), (2) Mechanical oscillators to exert sinusoidal forces in the vertical direction.

Detectors: (3) Seismometers to detect surface displacements in the vertical (V), longitudinal (L) and transverse (T) direction, (4) Pressure transducers to pick up pressure transfer in the V-direction.

Recorders: (5) Galvanometer-oscillograph (G.O.) to record time-displacement and time-pressure diagrams (t/V, t/L and t/T traces), and (6) Cathode-ray oscillograph (C.R.O.) to project soil-motion orbits (plane trajectories): T/V, T/L and V/L components or three dimensional trajectories: $T/V/L$ components.

The parameters were limited to:

distances, d, between
source and detector: $10 \text{ ft} < d < 200 \text{ ft}$
oscillator frequencies, n_c: $10 \text{ cps} < n < 60 \text{ cps}$
oscillator force vectors, F: $\pm 500 \text{ lb} < F < \pm 1500 \text{ lb}$
surcharges, W: $1500 \text{ lb} < W < 3000 \text{ lb}$

For experiments with sinusoidal waves, two items with respect to exciters and detectors are of primary importance. First, the exciting force vector must pass through the elastic center[7] of the vibrating system so that no moments are generated[6] and, second, the seismometers must record linear dis-

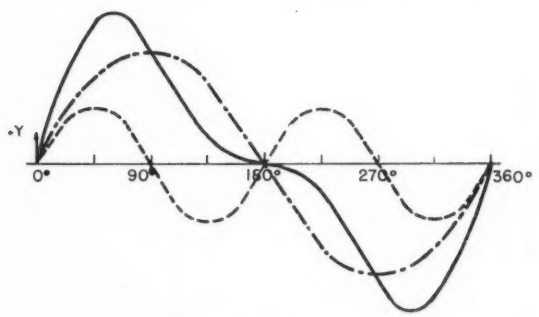
placements of either V or L or T components only and be nonresponsive to rotational motions.[9]

Nonperiodic Waves

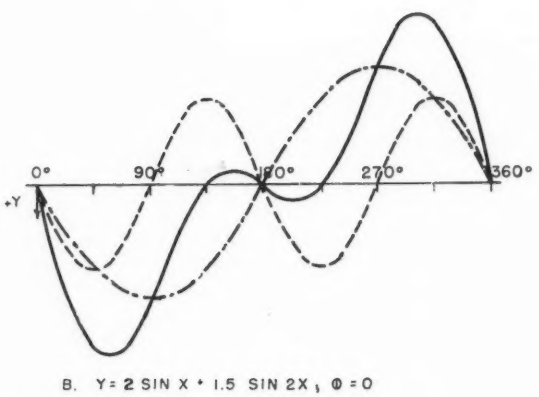
Nonperiodic force excitation by earthquakes or blasts are well known and are beyond the scope of this report. At large exciter-pickup distances, d, covering up to thousands of miles as in the field of seismology, the arrival of the first wave fronts permits a discrimination between various wave types.

However, at $d < 200$ ft, the leading and trailing waves are limiting the accuracy in determining the arrival time of wave fronts. Figure 3 demonstrates this case for hammer-blow excitation with $d = 25$, 50 and 75 ft. The resultant transients before and after the first arrival contain wave trains of numerous frequencies and may overlap partially. Their frequency spectrum is nonperiodic and cannot be produced as standing image on G.O. or C.R.O. screens. Hence, very accurate timing devices and high recording-paper speeds of G.O. are required. Trajectories of the surface motion form rather irregular patterns[13] which change substantially with minute changes of d.

Advantages and disadvantages of nonperiodic and periodic force excitation for short source-detector distance are summarized at the end of this report.



A. Y=2 SIN X + 1 SIN 2X ; Φ = 0



B. Y= 2 SIN X + 1.5 SIN 2X ; Φ = 0

Fig. 4—Superposition of two sinusoidal waves

Periodic Waves with Subharmonics

The purpose of this part is to show that a theoretical synthesis of sinusoidal waves containing the fundamental and the second harmonic coincides with experimentally obtained time-displacement records whenever the dynamic forces approach the static loads.

Superposition of Two Harmonics

Assume a wave of the form:

$$y = a_1 \sin x + a_2 \sin (kx + \varphi) \tag{1}$$

The maxima, b, of the resultant wave can be determined by equating the first derivative to zero:

For $y = 0$ $k = 2$ and $\varphi = 0$:

$$\frac{dy}{dx} = a_1 \cos x + 2a_2 \cos 2x = 0$$

or

$$4a_2 \cos^2 x + a_1 \cos x - a_2 = 0$$

and

$$\cos x = \frac{a_1}{8a_2} \pm \sqrt{\left(\frac{a_1}{8a_2}\right)^2 + \frac{1}{2}} \tag{2}$$

Let $a_1 = 2$ and $a_2 = 1$ or

$$y = 2 \sin x + 1 \sin 2x \tag{3}$$

then from eq (2):

$$\cos x = -\frac{1}{4} \pm \sqrt{\frac{1}{16} + \frac{1}{2}} = \begin{cases} 1/2 \\ -1 \end{cases}$$

$$x = \begin{cases} 60 \text{ deg} = x \text{ for } y_1{}^{\max} \\ 180 \text{ deg} = \text{inflection point} \end{cases}$$

or from eq (3):

$b_1 = y_1{}^{\max} = 2 \sin 60 \text{ deg} + 1 \sin 120 \text{ deg} = 2.598$

$b_2 = y_2{}^{\max} = 2 \sin 180 \text{ deg} + 1 \sin 360 \text{ deg} = 0$ (no 2nd crest)

In Fig. 4a this case is presented. The deviation from a sinusoidal wave at the inflection range, which becomes less noticeable when compressing the time axis, is not necessarily due to a nonsinusoidal force vector.

Let $a_1 = 2$ and $a_2 = 1.5$ or

$$y = 2 \sin x + 1.5 \sin 2x \tag{4}$$

then from eq (2):

$$\cos x = -\frac{1}{6} \pm \sqrt{\frac{1}{36} + \frac{1}{2}} = \begin{cases} 0.56 \\ 0.90 \end{cases}$$

$$x = \begin{cases} 56 \text{ deg} \\ 154 \text{ deg } 30' \end{cases}$$

or from eq (4):

$b_1 = y_1{}^{\max} = 2 \sin 56 \text{ deg} + 1.5 \sin 112 \text{ deg} = 3.0481$

$b_2 = y_2{}^{\max} = 2 \sin 154 \text{ deg } 30' + 1.5 \sin 309 \text{ deg} = -0.306$

This case is shown in Fig. 4b. The resultant wave is similar to experimentally obtained time to displacement records as for example in Fig. 1 (t-axis compressed).

All curves of this type are point- (skew-) symmetric for $r\pi (r = 0,1,2,3\ldots)$; the maxima, b_1 and b_2, are smaller than the algebraic sum of their components, a_1 and a_2.

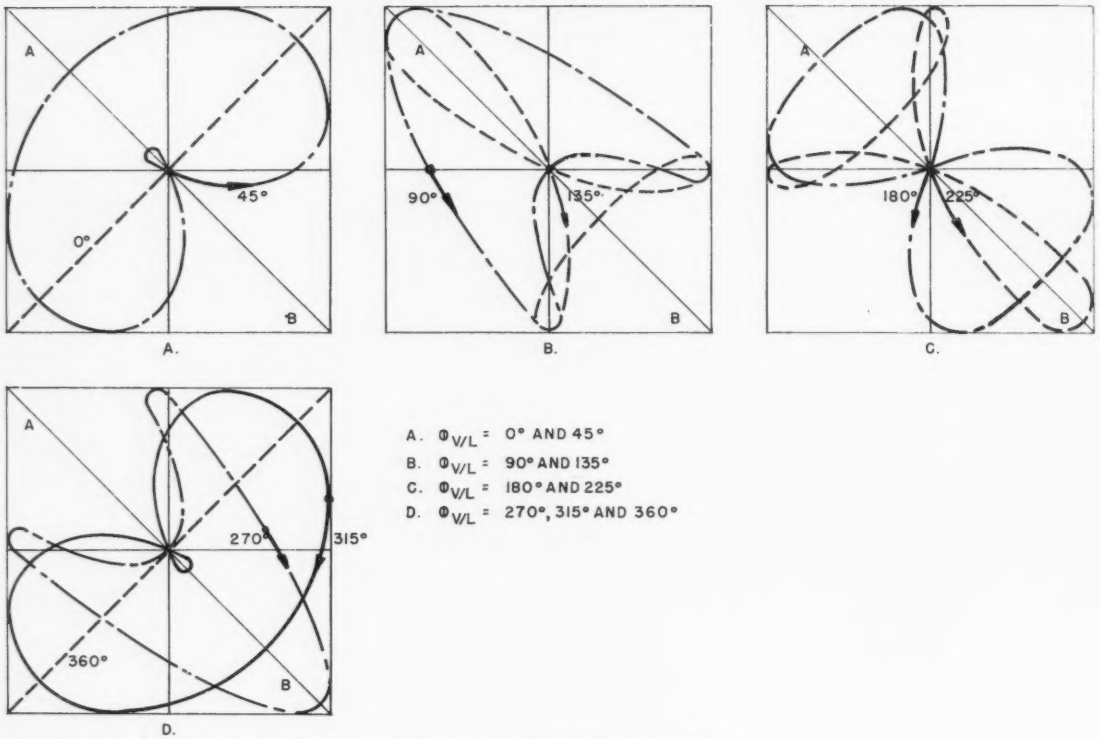


Fig. 5—Trajectories of four harmonics. $Y_L = 2 \sin x + 1.5 \sin 2x$, $Y_V = 2 \sin x + 1.5 \sin 2x$

Superposition of Four Harmonics

Assume two waves identical with the resultant composite wave presented by eq (4) (Fig. 4b)

$$y_1 = 2 \sin x + 1.5 \sin 2x \quad (5)$$

$$y_2 = 2 \sin x + 1.5 \sin 2x \quad (6)$$

where y_1 is a V component and y_2 is an H component (L or T) and $x = \omega_f t$.

Figure 5 demonstrates the sequence of trajectories by combining eqs (5) and (6) as they would appear on a C.R.O. screen. The phase angle, φ, between y_1 and y_2 is varied from 0 to 360 deg in steps of 45 deg. All orbits are mirror symmetric with respect to the 135 deg diagonal, A-B.

These rather simple waveforms already yield more complicated patterns (Lissajou's figures).

In the following studies the evaluation of time–displacement graphs (G.O.) and surface motion trajectories (C.R.O.), obtained from field experiments, is discussed. They refer to V and L components as traced by seismographs. The purpose is to determine the fundamental and subharmonic waves, including their phase relationship. Two typical cases are presented.

In the first case, assume distance, d = 30 ft.

The records shown in Figs. 6 and 7 are taken under identical conditions. An oscillator exerted a vertical sinusoidal force vector. The output of two seismometers was switched from G.O. (Fig. 6) to C.R.O. (Fig. 7) without stopping the oscillator or changing its operational characteristics.

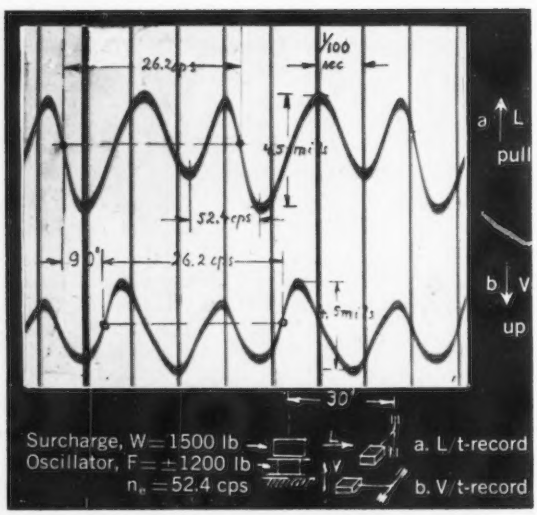


Fig. 6—Surface displacement of L and V components, G.O., with subharmonics $\varphi_{F/S}$ = 0 deg; $\varphi_{L/V}$ = 90 deg.

The time–displacement graph is not sinusoidal, indicating the presence of subharmonics ($F \leq W$). No rounding-off effects, that is, distortions at the maximum downward stroke, are noticeable as in Fig. 1. The orbit (Fig. 7) forms a standing pattern.

The necessary steps to determine the fundamental, subharmonics and phase angles are demonstrated graphically in Fig. 8.

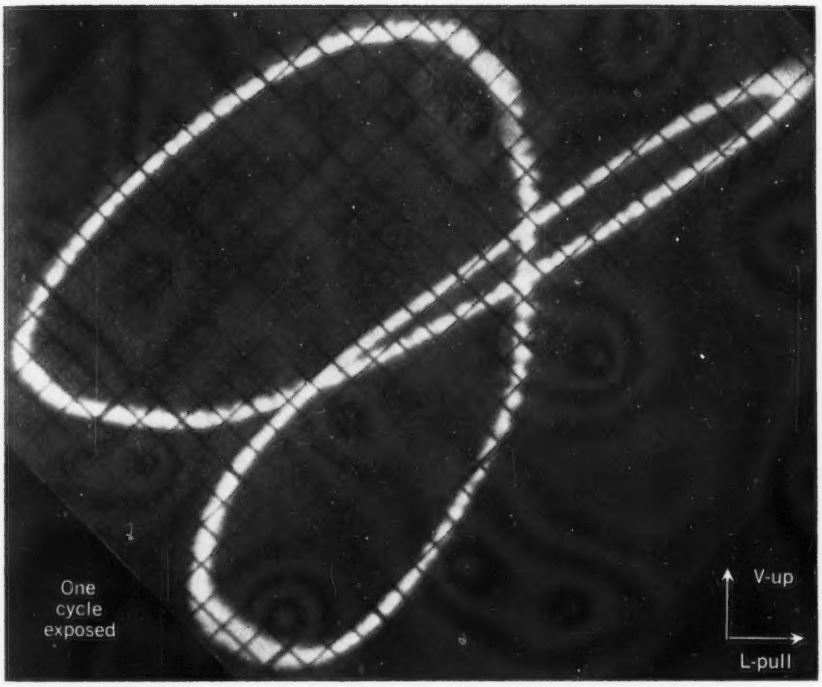


Fig. 7—Trajectory of surface motion with subharmonic. V/L record, C.R.O. For legend see Fig. 6. $\varphi_{F/S} = 0$ deg; $\varphi_{L/V} = 90$ deg.

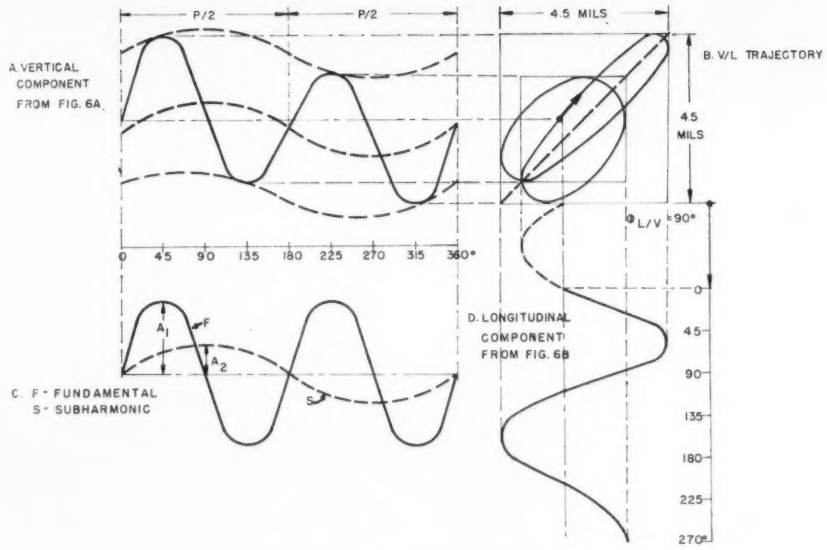


Fig. 8—Analysis of Figs. 6 and 7

1. The V and L components in Figs. 8a and d on the Y and X axis are copied from Figs. 6a and b.

2. These two components with a phase angle $\varphi_{L/V} = 90$ deg are combined into the trajectory, Fig. 8b. The circumscribing two squares must be tangential at the maxima and minima of V and L.

This trajectory is similar to the experimental findings, Fig. 7, neglecting the slight deviation in mirror symmetry with respect to the 45 deg diagonal.

3. The median between the two envelopes in Fig. 8a—dashed lines[14] represents the subharmonic and is plotted in Fig. 8c.

The results are:

Time-displacement waves: point symmetric for $r\pi (r = 0, 1,2,3\ldots)$.

Orbit: mirror symmetric for 45 deg diagonal and progressive.

Equations for V and L components:

Fig. 9—Trajectory of surface motion with subharmonic. V/L record, C.R.O. For legend see Fig. 10. d = 45 ft, $\varphi_{F/S} = 22.5$ deg, $\varphi_{V/L} = 45$ deg.

$y_V = y_L = 1.75 \sin 26.2 \times 4\pi t + 0.8 \sin 26.2 \times 2\pi t$

Phase angles: $\varphi_{FS} = 0$; $\varphi_{L/V} = 90$ deg.

Frequency ratio: $n_e/n_s = 52.4/26.2 = 2$.

Amplitude ratio: Fundamental/1st subharmonic $= a_1/a_2 = 2.19$.

In the second case, let distance, $d = 45$ ft.

A similar sequence, however, using the trajectory only, is shown in Figs. 9 and 10. Figure 9 represents the surface-motion trajectory (C.R.O.) of the V and L components; Fig. 10 shows the corresponding synthesis. It should be noted, however, that in this example phase angles and symmetry characteristics of the G.O. record differ from Fig. 4a.

The results are:

Time–displacement waves: neither point nor mirror symmetric.

Orbit: mirror symmetric for 45 deg diagonal and retrogressive.

Equations for V and L components:

$y_V = y_L = 1.5 \sin 17 \times 4\pi t + 1 \sin 17 \times 2\pi t$

Phase angles: $\varphi_{F/S} = 22.5$ deg, $\varphi_{V/L} = 45$ deg.

Frequency ratio: $n_e/n_s = 34/17 = 2$.

Amplitude ratio: Fundamental/1st subharmonic $= a_1/a_2 = 1.5$.

In this connection, it might be mentioned that it

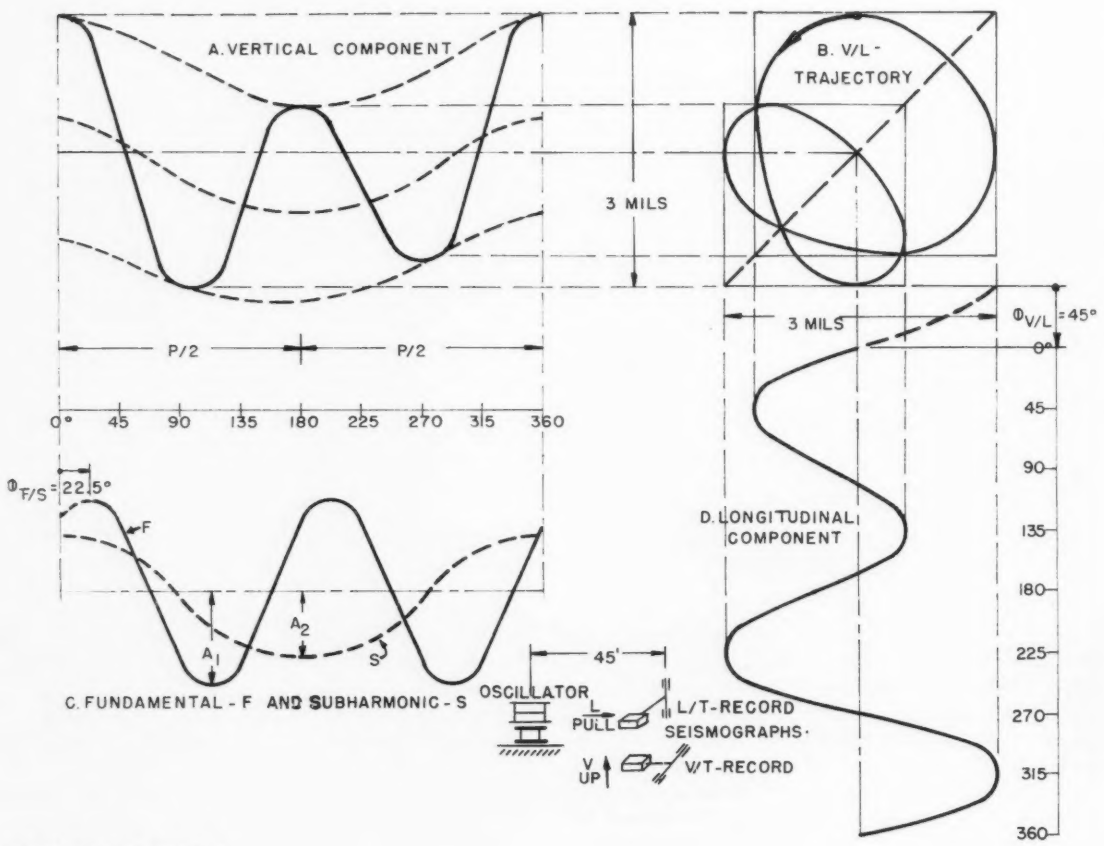


Fig. 10—Analysis of Fig. 9

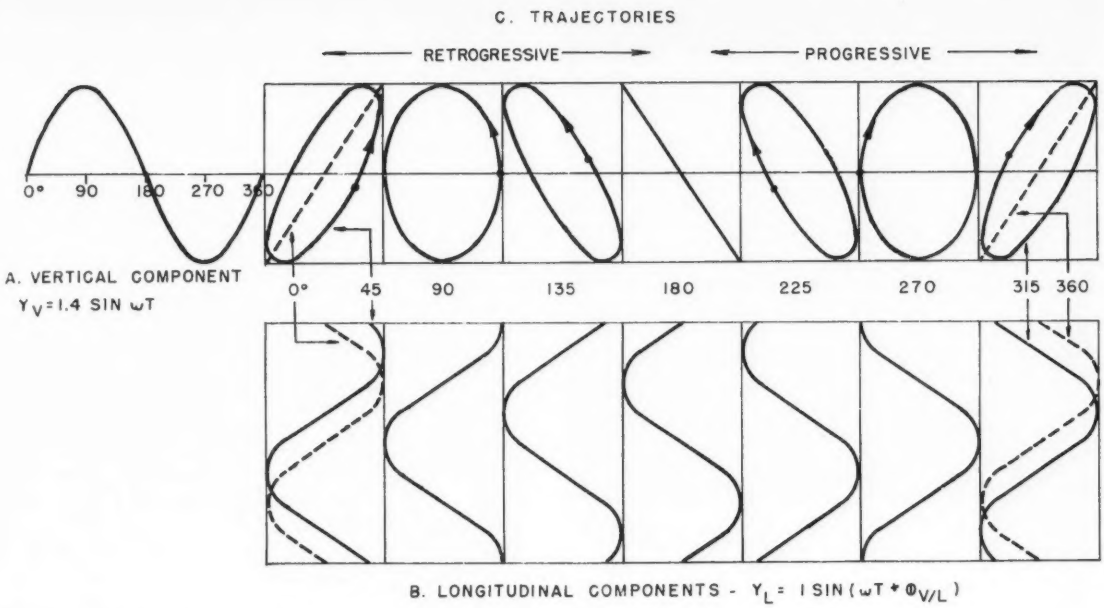

C. TRAJECTORIES
RETROGRESSIVE
PROGRESSIVE
0° 90 180 270 360
A. VERTICAL COMPONENT
$Y_V = 1.4 \sin \omega T$
0° 45 90 135 180 225 270 315 360
B. LONGITUDINAL COMPONENTS - $Y_L = 1 \sin(\omega T + \Phi_{V/L})$

Fig. 11—Surface displacement of V and L components without subharmonics. V/L ≅ 1.4

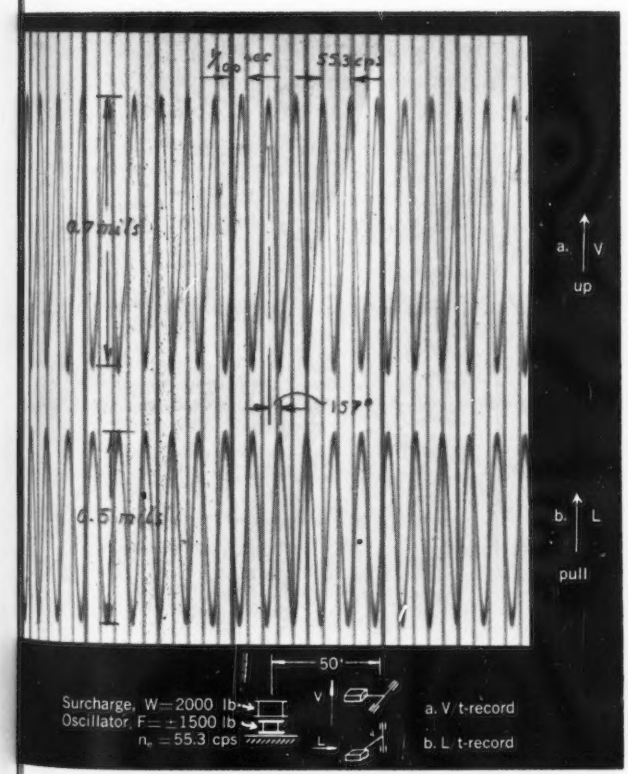


Fig. 12—Surface displacement of V and L components without subharmonics, G.O. W/F — 1.67, V/L = 1.4, $\varphi_{V/L} = 157$ deg

is common practice in a-c circuitry to reproduce these or even more complicated patterns by using a C.R.O. as some kind of "small scale" analog-computer. A-c voltage input signals on the X and Y axis must be attenuated to the same characteristics as the displacement–time curves with their phase angles corresponding to the appropriate values.

From this investigation the conclusion may be drawn that an evaluation of displacements due to excitation of sinusoidal waves with subharmonics is somewhat cumbersome. In particular, it is difficult to decide what type of waves are predominant (for example: distortional, dilatational, etc.).

For this reason, the excitation of sinusoidal waves without subharmonics will be discussed in the next section.

Periodic Waves Without Subharmonics

The purpose of this section is to show the advantages referring to sinusoidal waves without subharmonics, particularly to determine plane orbits (V/T trajectories) and space orbits ($V/L/T$ trajectories), as well as phase velocities.

V/L Plane

Two sinusoidal time–displacement waves are assumed, that is, $F \ll W$. In Fig. 11 this case is demonstrated for a V/L ratio of 1.4. This ratio corresponds to a Rayleigh-type wave.[15] Figure 11a represents the V component, Fig. 11b the L components and Fig. 11c the resultant trajectories. The phase angle, $\varphi_{V/L}$, is varied from 0 to 360 deg in steps of 45 deg. The surface-motion orbits

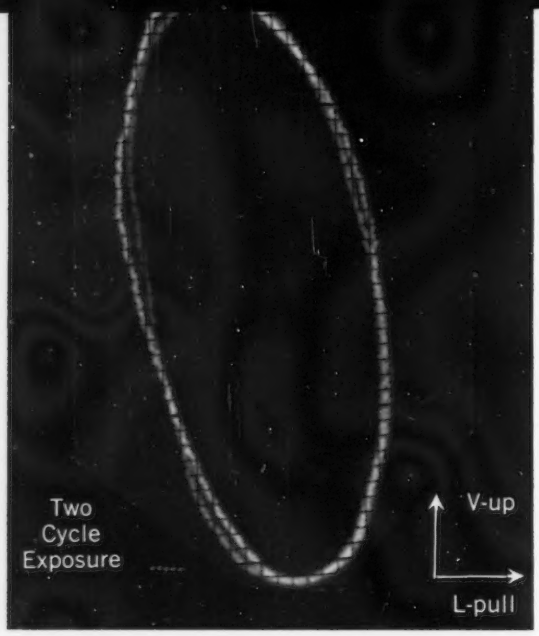


Fig. 13—Trajectory of surface motion without subharmonic. V/L-record, C.R.O. For legend see Fig. 12

degenerate from straight lines (diagonals) to elliptic orbits and back into straight lines (diagonals). For phase angles: $0 < \varphi_{L/V} < 180$ deg, the motion is retrogressive; for $180 < \varphi_{L/V} < 360$ deg the motion is progressive.

Figures 12 and 13 are the results of field experiments. In Fig. 12, the time–displacement records of the surface motion are traced on a G.O. Both the V and L components indicate sinusoidal images without subharmonics. The corresponding trajectory in Fig. 13 was photographed by transferring the seismometer output to a C.R.O. without stopping or changing the oscillator operation. Almost perfect elliptic orbits are characteristic in case of absence of subharmonics. Due to unavoidable line-voltage fluctuations, i.e., change in gain of amplifiers, first and second exposure do not coincide completely.

A phase angle $\varphi_{V/L} = 157$ deg can be deducted from Figs. 12 or 13, a retrogressive orbit from Fig. 11.

Elliptic orbits, due to sinusoidal force excitation, provided $F \ll W$, facilitate phase-velocity determinations. This velocity is important in cases where only two waves are predominant, for example, when one surface and one reflected body wave combine[16] into a Rayleigh-type wave.

Let two detectors be located at 2 ft distance on a straight line radiating from the disturbance and assume an exciter frequency $n_e = 20$ cps (Fig. 14d).

The output of the two seismometers, set up for vertical surface displacement, is fed into the X and Y axis of a C.R.O. The gain of the amplifiers of both axis are attenuated so that their outputs are equal in magnitude to the corresponding sides of the circumscribing square in Fig. 14c. Furthermore their position must coincide with the centerlines e-f and g-h of this square.[14]

Three resultant orbits are shown in Fig. 14c. Phase angles and velocity are plotted on the 135 deg diagonal. The scale is obtained by projecting the angle from the Y component on the diagonal, multiplied by the factor two. This scale yields

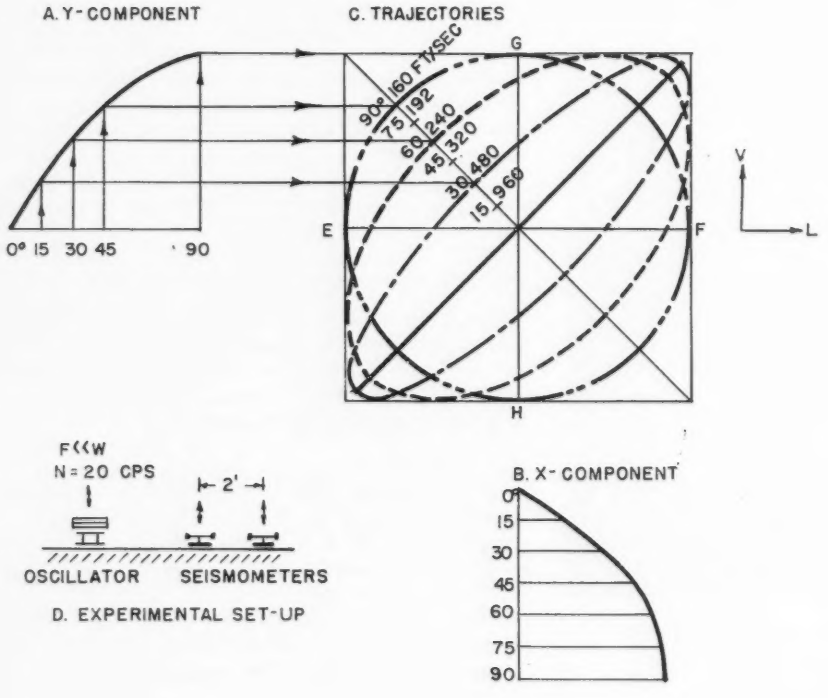


Fig. 14—Phase velocity determination from trajectory-image on cathode-ray oscillograph

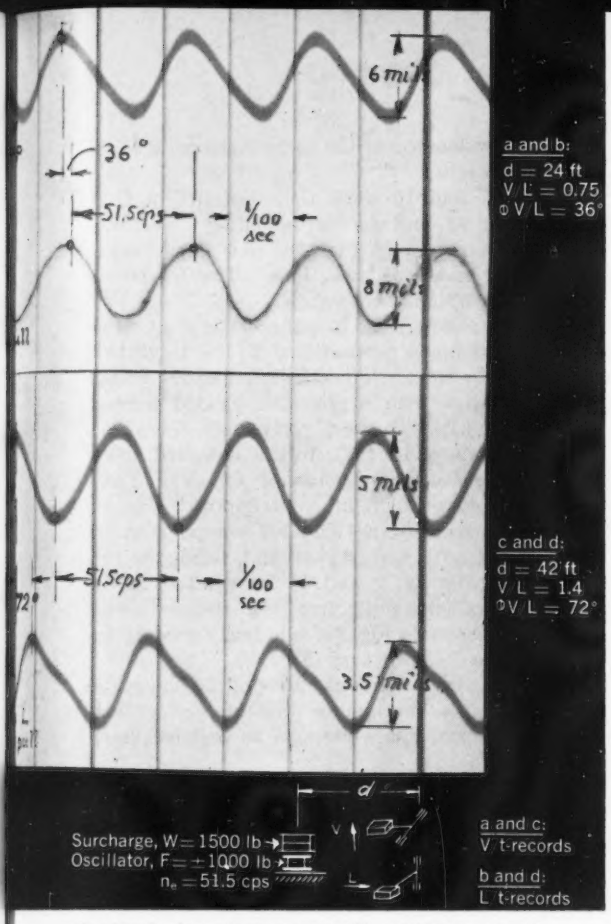


Fig. 15—Surface displacement of L and V components without subharmonics, G.O. W/F = 1.5

the corresponding phase angles from 0 to 90 deg and velocities from 160 to 960 ft-sec^{-1}.

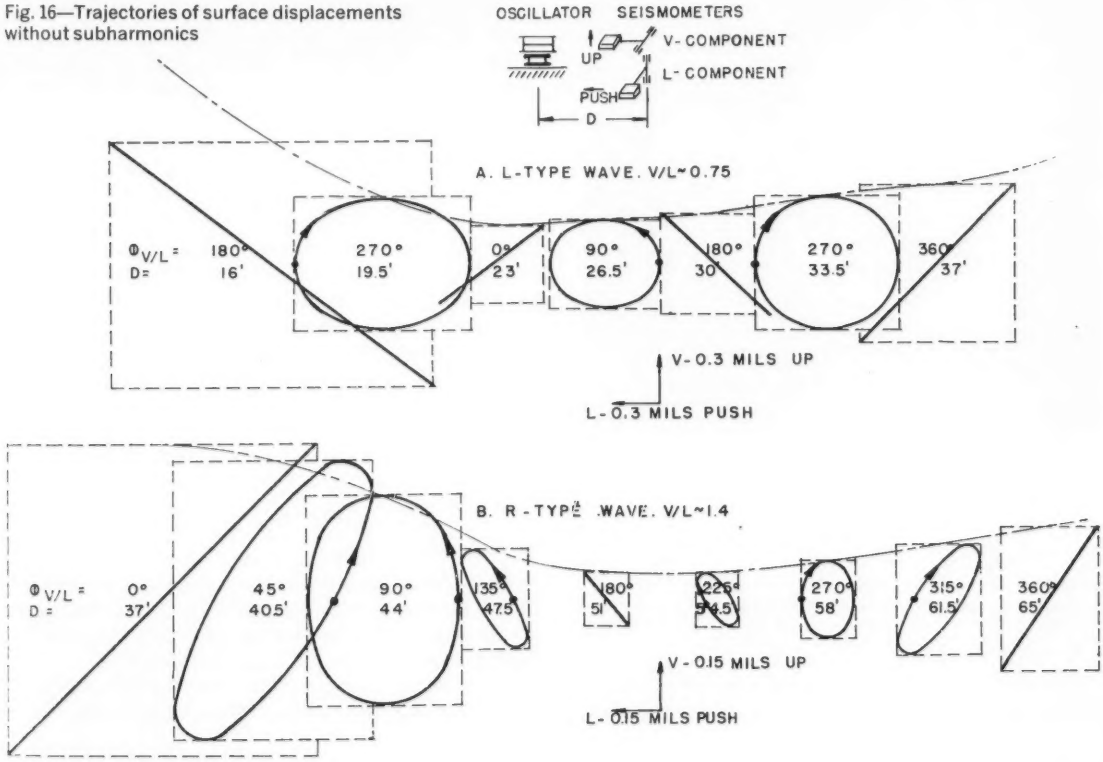
All orbits cross the velocity scale at right angles. Hence, this method seems more accurate than measurements of small time differences obtainable from wavepeak shifts on displacement–time records (Fig. 12).

Previous experiments have shown that refraction effects from subjacent strata may occur within a limited distance, d, between source and detector.[3, 4, 16] A refracting horizontal plane existed at about 11-ft depth below the surface. The distance, d, ranged from about 12 to 200 ft.[16]

In Fig. 15, the V and L components of time–displacement records (G.O.) of the surface motion at $d = 24$ ft and $d = 42$ ft are presented, where d is in the above-mentioned range. A slight deviation from the sinusoidal wave in trace on Fig. 15d (subharmonic contents less than in Fig. 4a) might be discarded. All four components on these records are attenuated to almost equal magnitude to facilitate their evaluation. For $d = 24$ ft, a phase angle between V and L components $\varphi_{V/L} \cong 36$ deg and for $d = 42$ ft a phase angle $\varphi_{V/L} \cong 72$ deg can be computed. The corresponding amplitude ratios V/L are $\sim$0.75 and $\sim$1.4.

A change in trajectories with respect to d is illustrated in Fig. 16. The envelope (dash-dot line) for the V components is taken from displacement versus distance curves of previous investigations.[17,18] For 16 ft $< d <$ 37 ft, the L components (compression-

Fig. 16—Trajectories of surface displacements without subharmonics



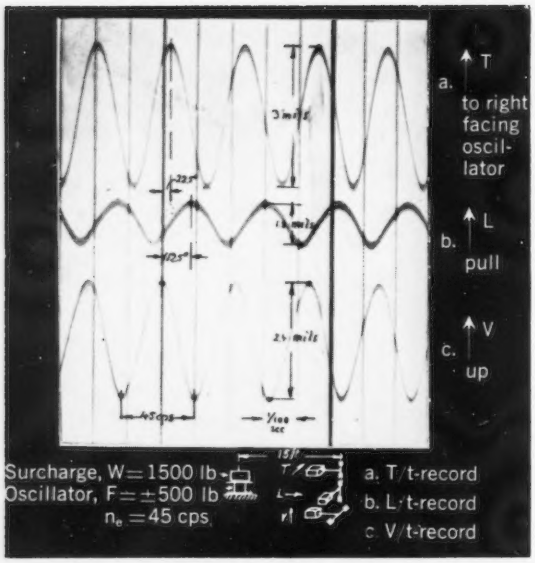


Fig. 17—Surface displacement of T-, L-, and V-components without subharmonics, G.O. d = 15 ft, $\varphi_{V/L} = 112.5$ deg; $\varphi_{V/T} = 22.5$ deg; W/F = 3

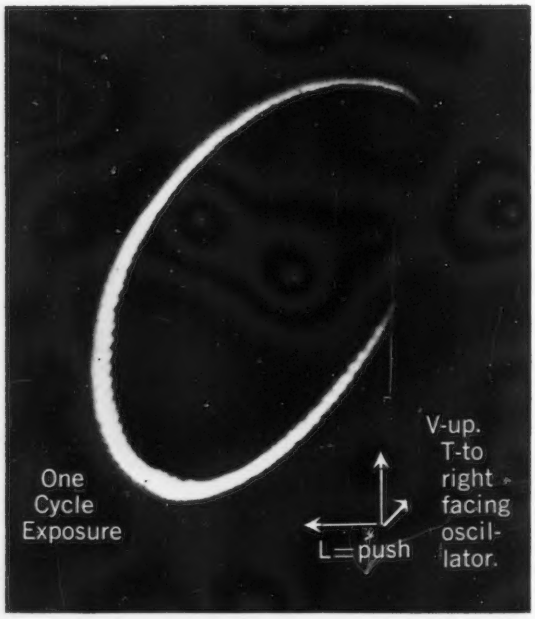


Fig. 18—Space trajectory of surface motion without subharmonics. V/L/T — record, C.R.O. For legend see Fig. 17

type waves), for 37 ft $< d <$ 65 ft the V components (Rayleigh-type wave, characterized by the amplitude ratio of 1.4) seems to become predominant.

V/L/T Space

In order to investigate soil-surface motion in space, three seismometers, set up for the V, L, and T components, were located at the same distance, d = 15 ft, from the exciter.

Figures 17 and 18 show their output: a G.O. record in Fig. 17, and the corresponding trajectories on a C.R.O. screen in Fig. 18. All images were taken under identical conditions. The legend on Fig. 17 lists the significant values.

The T component is fed into the Z axis of a C.R.O. (Fig. 18) and made proportional to the brightness or width of the trace. Thus, scanning of the photographic negative with a photocell yielded a trace coinciding closely with the T component (Fig. 17a).

In Fig. 19 the space trajectory is analyzed, using the time-displacement records of Fig. 17. First, the V and L components are superimposed (Fig. 19, a, b and c); second, the V and T components are combined (Fig. 19, a, d and e); and, third, the two trajectories (Fig. 19, c and e) are plotted in the form of an isometric projection (Fig. 19f).

The orbit shown in Fig. 19f is in fairly good agreement with the C.R.O. record (Fig. 18).

All previous investigations indicate that sinusoidal waves without subharmonics facilitate the evaluation of plane and space motions as well as phase-velocity determination.

Conclusions

The advantages and disadvantages of nonperiodic and periodic excitations for evaluating soil-motion records may be listed as follows:

Nonperiodic Excitation

ADVANTAGES—Nonperiodic excitation due to explosive charges (blasting) or hammer blows represents the only method to investigate the effects at large source-detector distances. This is of particular importance for simulating earthquake phenomena or for subsurface explorations.

From the arrival of the first wave fronts, velocities of various types of waves can be determined since the leading and trailing waves of each wave packet are of minor significance at $d \gg 200$ ft.

DISADVANTAGES—Magnitude, frequency, position and direction of the excited force vectors are difficult to reproduce and no independent and controllable variation of these parameters is possible.

The induced transients contain numerous frequencies and no standing wave patterns can be traced.

Very accurate timing of the recording mechanism is essential and the nonperiodic soil-motion orbits change with minute changes in location of the detectors.

Periodic Excitation

ADVANTAGES—Magnitude, frequency, position and direction of any excited sinusoidal force vectors can be reproduced and each of these parameters may be kept constant or varied independently.

A stable dynamic equilibrium of the generated stationary soil-wave patterns requires no restriction

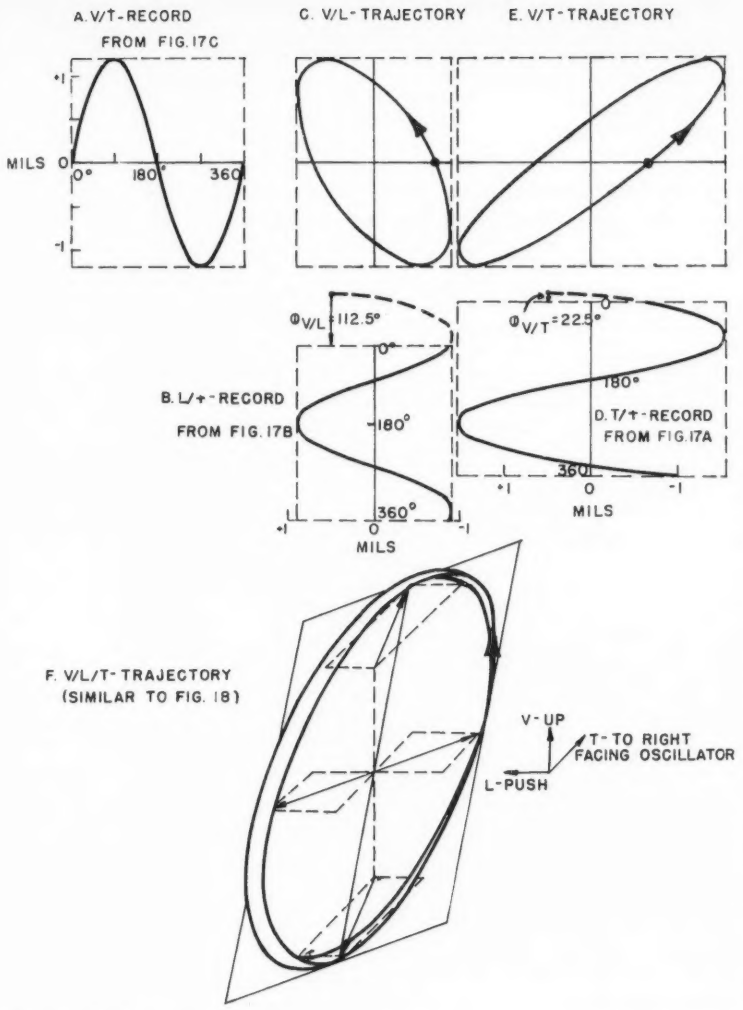


Fig. 19—Analysis of Figs. 17 and 18

in timing of the recorded mechanism, and standing plane—as well as triaxial—orbits can be projected on a cathode-ray oscillograph.

No transient phenomena disturb the records.

DISADVANTAGES—Source-detector distances are restricted to small ranges when compared with blast excitation. A separation of various wave types is not always possible.

Summarizing these conclusions, it can be stated:

For many engineering problems, such as vibration transmission on highways, airfields, machine foundations and for soil compaction, shorter source-detector distances are predominant.

Sinusoidal-force excitation, in particular without inducing subharmonics, seems to present a helpful supplementary research method.

The question whether vibratory compactors are more efficient with larger rather than smaller dynamic force vectors, when compared with their dead weight, requires further investigation.

Acknowledgment

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The continued interest of E. C. Easton, dean of the College of Engineering, and of J. J. Slade, Jr., research director of the Bureau of Engineering Research at Rutgers University, The State University of New Jersey, is very much appreciated.

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Simplified Equipment for Photoelastic Studies of Propagating Stress Waves

Apparatus described by author provides control over the observed progress of the wave and permits photography of the wave with conventional cameras

by Herbert Becker

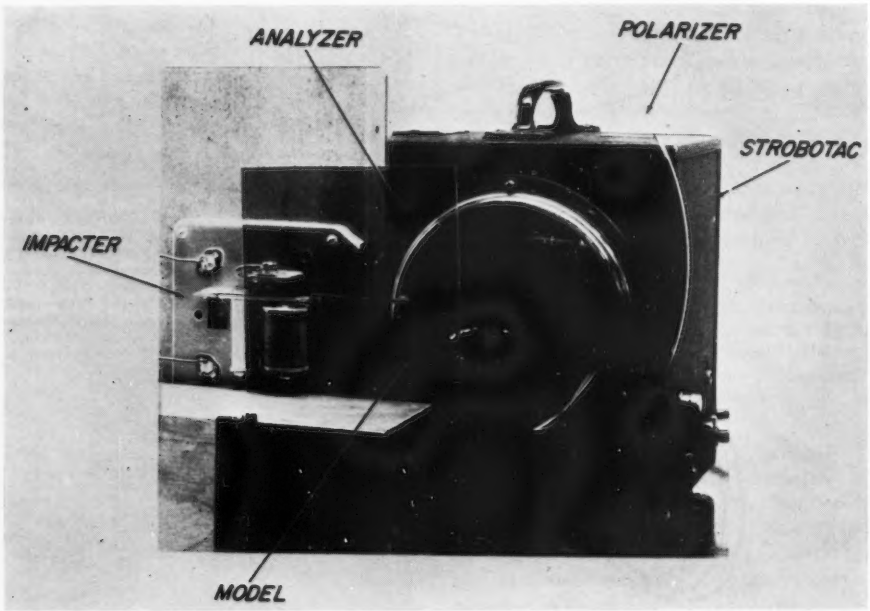

Fig. 1—Photograph of experimental arrangement

SUMMARY—The propagation of stress waves generated by impact may be observed photoelastically with the use of the simple experimental arrangement described herein. In addition to providing control over the observed progress of the wave, the apparatus permits photography of the wave with conventional cameras. The equipment may be used not only for scientific experiment, but also for classroom demonstration.

Introduction

Past experimental investigations of the progress of an impact-generated stress wave have two features in common: only a single impact was studied at one time, and there was no visualization of the event. Photoelastic investigators have followed in this pattern since Tuzi and Nisida.[1] The usual approach has been the recording of an event by high-speed photography and subsequent optical projection of the record with conventional equipment. This usually requires use of a special triggering system to synchronize the flash, the camera and the impact event. Durelli and Riley[2] employed one of the simplest experimental arrangements for this purpose by using a flash bulb source and a Fastax camera at speeds as high as 12,360 frames per second, together with urethane rubber models for which the longitudinal sound propagation speed is of the order of 2000 ips.

From the standpoint of experimental photoelasticity, however, it is desirable to observe the propagating wave without resort to high-speed photography. This was the stimulus for construction of the apparatus described herein, which employs the stroboscope principle. Hypothetically, a periodically flashing light source in synchronization with a repeated impact should make the propagating wave appear stationary. The behavior of such a system

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is depicted in the accompanying photographs and is described in the following paragraphs.

Experimental Arrangement

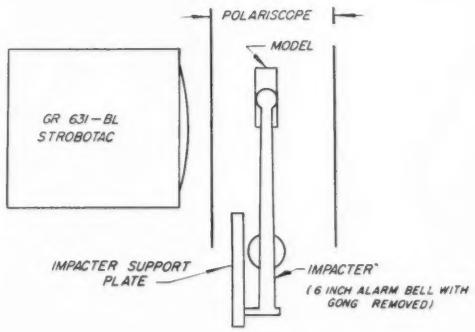
The equipment (Figs. 1 and 2) consisted of a General Radio Type 631-BL Strobotac and an alarm bell with the gong removed. The model, placed in a polariscope, was struck repeatedly by the bell clapper (at roughly 60 cps in these experiments) with the Strobotac adjusted approximately to the same rate. By controlling the Strobotac rate while observing the waves, they were made to appear to travel rapidly, slowly, stop altogether, or even reverse. With the apparent wave stopped in any position, it was possible to examine the fringes and study isoclinics, and to record them by photography or by sketching. Furthermore, variations in the problem, such as shifting the position of impact or varying the striking energy, were easily studied.

Material

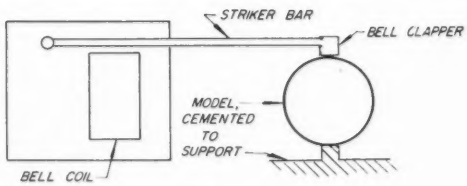
The material used in these preliminary studies was highly plasticized HYSOL 6000-OP, which has a static material fringe value of about 1 lb per in-fringe. The mechanical properties of this material were not investigated during the development of the wave-visualization equipment. However, it is expected that viscoelastic effects would be present, as Durelli and Riley reported for the urethane rubber which they used.[2]

Since the New York University models were cemented to a base pad, the reflections from the pad would continue indefinitely if the model material were perfectly elastic. However, preliminary observations of the behavior of the wave in the NYU models revealed gradual decay and eventual cessation of activity, indicating the presence of damping. In the 1-in. disk (Figs. 3, 4 and 5), for example, four full cycles of reflection (alternating between compression and tension in each cycle) were observed before the reflections decayed to very small values. The nature of the reflection stress was easily checked after the bell clapper left the model by watching the motion of the model as it bounced up and down.

The value of c for the plastic used in these experiments was found to be of the order of 1000 ips based on a preliminary check. This is considerably less than the theoretical 60,000 ips linear velocity of a more conventional photoelastic material such as unplasticized epoxy or CR-39, which would require a shorter-duration flashing source than used here in



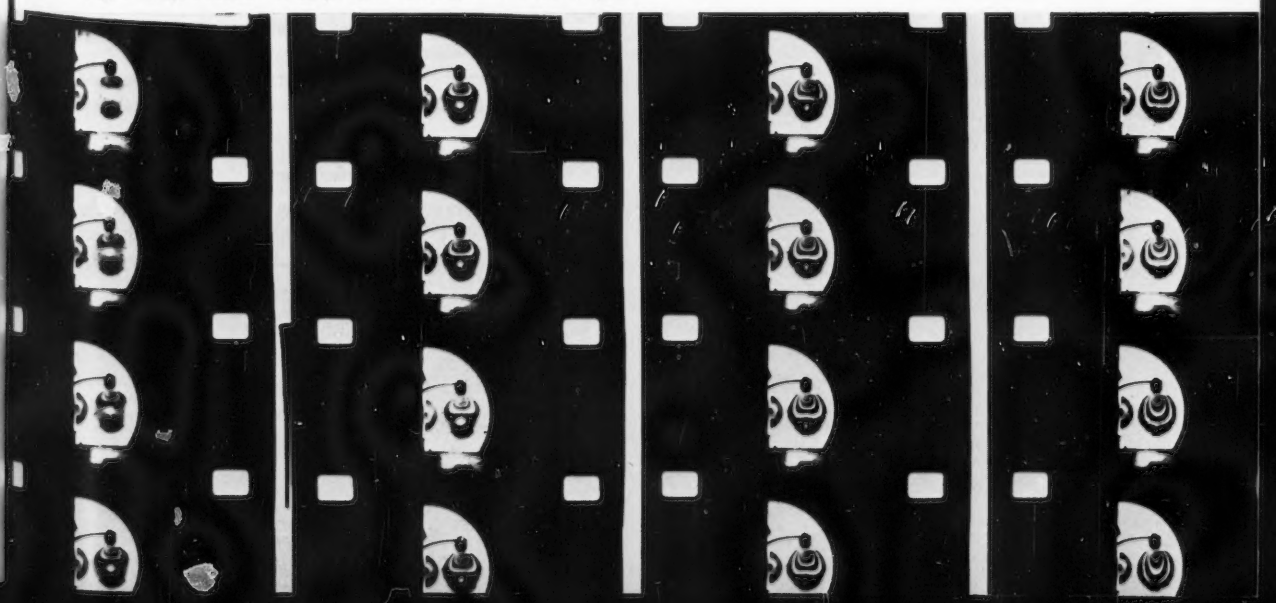
TOP VIEW OF GENERAL ARRANGEMENT



DETAIL OF IMPACTER — MODEL ARRANGEMENT

Fig. 2—Details of experimental arrangement

Fig. 3—Reproduction of strip from movie of disk under impact



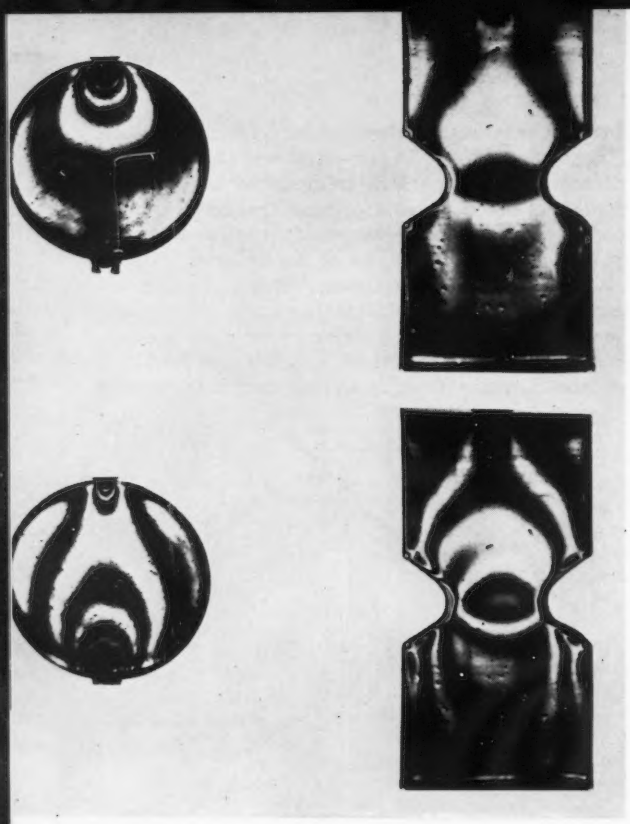


Fig. 4—Still photographs of fringe patterns in disk and notched bar under impact

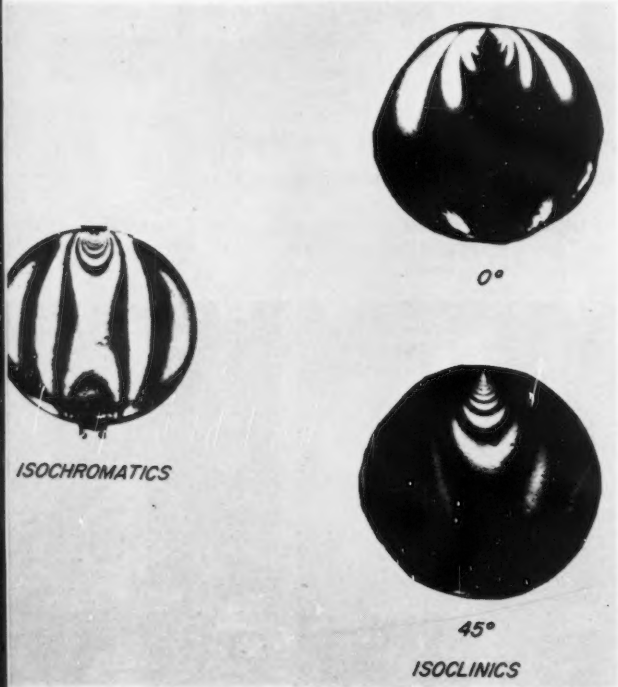


Fig. 5—Isoclinics in impacted disk, the fringe pattern for which is shown at the left

order to visualize the waves clearly, and presumably would also necessitate a stronger impact than available with the equipment used in the present arrangement because of the much larger material fringe value of CR-39.

Photography

The flash duration of the Strobotac is approximately 10 micro-seconds. With a 60-cycle flash frequency, clear movies and stills were obtained with little effort. At a 1:1 magnification, stills were made on Tri-X-Pan film at an aperture of f2 using the shutter at $^1/_{50}$ sec to ensure one exposure. By adjusting the Strobotac flashing frequency so that the wave appeared to move slowly, it was only necessary to wait until the desired configuration appeared. The camera shutter was then tripped to record the visualized image.

Movies were made on Tri-X-reversal film at f2.5 at 32 frames per second, which guaranteed only one exposure per frame. The camera recorded the visualized event in this case also.

Photoelastic Data

The photoelastic information recorded with this equipment appears in Figs. 3, 4 and 5. The fringe patterns and isoclinics in the disk and the fringes in the notched bar are typical of the well-defined patterns obtainable.

Advantages of the wave-visualization procedure over present methods of obtaining dynamic photoelastic data are:

1. Location of the zero-order fringe, or compensation to establish fringe order, throughout the entire impact event.
2. Moving the polariscope to permit close observation of any region of a large model (for example, at a large distance from the impacted end of a long bar) while the apparent wave is propagating.
3. Leisurely study of fine detail in the stress pattern during the process of development, or in the "frozen" state.
4. As mentioned previously, freedom in isoclinic examination.
5. Photography may be limited to stills, or may be omitted altogether.
6. No special triggering arrangement is necessary to synchronize the light source, camera and impact event.

Acknowledgment

The experimental arrangement described herein was constructed by Angelo Colao, Ronald Brown and Jack Morris, while the models were machined by Irving Silverberg.

References

1. *Tuzi, Z., and Nisida, M., "Study of Stresses Due to Impact by Photoelasticity," Inst. Phys. and Chem. Res. Japan—Bul., 13, No. 3, 148–162 (1934).*
2. *Durelli, A. J., and Riley, W. F., "Experiments for Determination o Transient Stress and Strain Distribution in Two-Dimensional Problem," J. Appl. Mech., 24, No. 1, 69–76 (Mar. 1957).*

sesa news

SESA Holds First International Congress in New York City

The First International Congress on Experimental Mechanics provided a full and varied program during three busy days of technical and social activity from Nov. 1 to Nov. 3, 1961, at the Hotel New Yorker, New York City.

Sponsored by the Society for Experimental Stress Analysis and cosponsored by the Office of Naval Research, the Army Research Office and the Air Force Office of Scientific Research, the Congress was arranged and managed by the Metropolitan New York Section of SESA.

Eminent support of the Congress was given by the engineers and scientists who traveled from more than half-a-dozen countries abroad to present papers and to attend the proceedings.

A full program kept some 300 participants engaged in a busy schedule that included daily technical sessions, the annual Murray Lecture, a manufacturer's equipment exposition, educational lectures, a banquet address by a United Nations Minister, a special ladies' program and numerous committee and business meetings.

President Kennedy Sends Greetings

SESA President Daniel C. Drucker opened the meeting with a message from the President of the United States. Congratulating the members of SESA for convening the Congress and helping to promote international understanding, President Kennedy extended an official welcome to the participants from overseas to "unite with us in fashioning from our mutual efforts in research and technological innovation an environment in which the sinew of science can be put to work for pursuits of peace."

THE WHITE HOUSE
WASHINGTON

STATEMENT FOR THE FIRST INTERNATIONAL CONGRESS ON EXPERIMENTAL MECHANICS

I should like to extend congratulations to the scientists and engineers of the Society for Experimental Stress Analysis for sponsoring the First International Congress on Experimental Mechanics. I applaud your Society for its initiative and pursuit of international understanding in convening from around the Free World your associates in the several disciplines of science and technology which converge on experimental mechanics.

Through your Society I wish to convey a cordial welcome to the scientists and engineers who are gathered at the Congress and express a sincere hope that they unite with us in fashioning from our mutual efforts in research and technological innovation an environment in which the sinew of science can be put to work for pursuits of peace.

John F. Kennedy

A message from President Kennedy

Continuing with his own words of welcome, President Drucker expressed the Society's appreciation for the interest shown by the foreign visitors in coming here to present their work and to the authors and participants from this country for their contributions to the field. After a brief description of SESA activities during the past year, President Drucker outlined some of the plans being made for the future growth of the Society. He then turned the meeting over to E. R. Lewis, chairman of the first technical session.

Technical Sessions Are Primary

As the primary purpose of the Congress, technical sessions were held daily from Wednesday morning through Friday noon. In all, 24 papers were presented ranging in subject matter from studies of specific structures to surveys describing the scope of work undertaken at some European laboratories. The largest number of papers was concerned with general studies of the behavior of basic structural types, such as cylinders or plates. Next in order were the evaluation of methods of experimental techniques, and the development of new measuring devices or instruments. Many papers combined aspects of these approaches in unique and ingenious solutions to particular problems.

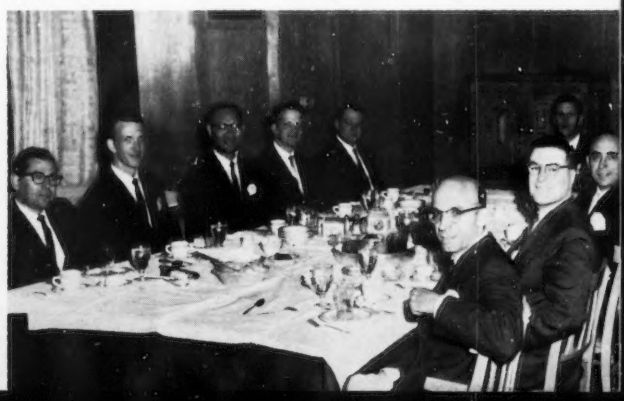
Among the authors who presented papers at the Congress, 11 were from foreign countries and 13 from the United States. The foreign nations represented were Australia, England, Italy, Japan, Netherlands, Scotland, South Africa and Sweden. The excellent response from abroad was a fine tribute to the spirit of international cooperation that helped to make the 1961 Congress a success.

Orowan on Crystal Structure

Early Friday afternoon the technical program culminated in a special event, the annual Murray Lecture, for

A busy time at the registration desk on Wednesday morning

At the Authors' Breakfast on Wednesday, the authors are (far side) E. Sevin, J. R. Steele, S. S. Kuo, H. Wieringa and D. P. Ankeney. At near side are B. E. Rossi, executive secretary; D. C. Drucker, SESA president; E. R. Lewis, chairman of Metropolitan New York Section; and C. H. Willer, D. L. Vidmark of SESA staff



Words of welcome were given by President Drucker at the opening session

Luncheon meeting of the Journal Advisory Committee. Left to right: C. H. Willer, Treasurer W. M. Murray, D. L. Vidmark, B. E. Rossi, President Drucker, Past-president B. H. Lazan, F. B. Stern, R. Guernsey, Vice-president Irwin Vigness

Exhibits Committee making plans for the future. Left to right: Greer Ellis, Lee Weymouth, Chairman F. B. Stern, Jr., D. L. Vidmark and Jerome Catz

Chairman R. Guernsey (left) having a discussion with the Papers and Proceedings Committeemen C. S. Ades, A. Philips, R. Thomson, E. K. Lynn, C. S. Barton, D. M. Cunningham and W. J. Blackstock

Membership Committee Chairman Ray Gallant (left) looks over rising membership curve with Executive Secretary Rossi, Local Sections Committee Chairman Clarence Smith and R. C. A. Thurston

which an outstanding scientist or engineer is invited to speak. This year, Egon Orowan, who holds the chair of George Westinghouse Professor of Engineering at MIT, was the honored guest. Dr. Orowan is one of the scientists credited with the independent proposal of the dislocation theory in crystal-lattice structure. Recent experiments have dramatically confirmed this theory and have led to important conclusions regarding crystal growth and the behavior of lattice structure under stress. Dr. Orowan discussed some of the implications involved in recent findings, pointed out the limitations, and suggested future lines of inquiry.

Exhibits Arouse Lively Interest

One of the most important features of the Congress was the equipment exposition held on the mezzanine floor of the hotel where 18 manufacturers' exhibits attracted a lively audience. In addition, educational displays drew considerable interest. The exposition opened early Wednesday morning and continued throughout the three-day period until early Friday afternoon.

The exhibits constituted a representative cross section of the equipment that is useful in the field of stress analysis and in the associated areas of study. Some of the equipment shown ranged from general-purpose strain gage and strain-indicating devices to an automatic 96-channel data-acquisition system with digital readout and chart recording. Optical methods of strain measurement were represented by complete polariscope systems of the transmission type, as well as those for analysis by birefringent coatings. There were also examples of eddy-current instruments, highly versatile universal testing machines, programming equipment, automatic wave analyzers, radiotelemetry systems and many other devices. One torque-measuring device sensed changes in magnetic permeability due to applied stress and thus avoided mechanical coupling. Much of the equipment displayed was of recent development; some was entirely new.

One of the most popular devices of this year's exposition appeared to be the semiconductor transducer. This sensitive solid-state device turned up in several different applications, such as strain gages, accelerometers, torquemeters, load cells, pressure cells and pickups. Their range varied from million-pound load cells to tiny instruments that can be implanted in muscle tissue to give telemetry signals.

The exhibitors were well pleased with the interested and responsive audience in attendance.

Educational Lectures

Two exceptionally fine educational lectures were presented by SESA members on Wednesday evening. The first lecture, given by C. C. Perry of Wayne State University, was an intensive, three-hour talk on the fundamentals of strain gages and their application, as well as other basic methods of measurement in stress analysis. This lecture was intended as a help to undergraduate students in the metropolitan area.

The other lecture dealt with more advanced subjects. Burton Erickson of Polytechnic Institute of Brooklyn discussed the measurement of transient strains at elevated temperatures in the light of recent work he has done in this field. Herbert Becker of New York University covered recent experiments in photothermoelasticity.

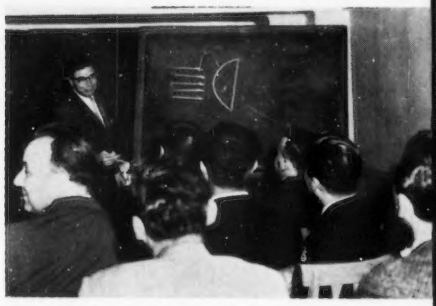
U. N. Minister Addresses Banquet

The outstanding nontechnical highlight of the 1961 Congress was the banquet address by Emile J. Lapian, Indonesian Minister to the United Na-

The ladies about to embark on a sight-seeing trip of New York City. Left to right, the Mmes. H. P. Adam, W. K. Maddox, M. Meier, H. Matlock, J. Walmsley, W. C. Young, H. Hiltscher, D. Pasquine, T. Braunstein, S. Black, R. R. Walker, C. Bert, J. Joyce and V. Dawson

The Standing Committees Dinner brought together many old friends and loyal SESA members, most of whom are shown above

C. C. Perry addressing the first educational lecture on stress analysis. He spoke for three solid hours before an interested audience



Burton Erickson makes a point during his lecture on advanced techniques at the educational session

During another part of the educational lectures, Herbert Becker brought out some recent work on photothermoelasticity

tions. Minister Lapian presented the background of the recent struggle over the appointment of a Secretary-General for the U. N. The present compromise, Mr. Lapian explained, is only temporary because the U. N. Charter itself no longer reflects the change in world balance of power which has shifted to the noncommitted nations of Asia and Africa. However, even before a Charter revision can accomplish due representation, the problem of the recognition of Red China must be solved in order to unblock the present stalemate between the U. S. and Russia.

The banquet itself was a complete social success. Preceded by a social hour, the diners began in good spirits. A trio played music for entertainment and, later, for informal dancing.

Ladies Enjoy Special Program

While technical matters were occupying the attention of their husbands, a good contingent of the ladies enjoyed the special program arranged for their pleasure. On Wednesday afternoon, a sight-seeing trip was arranged by chartered bus to many points of interest in New York City, including the famous Chinatown section. On Thursday, a more sophisticated venture took the ladies to visit a fashion show, where everyone had a fine time viewing the latest styles. On Friday they visited the United Nations Building.

Committee and Business Meetings

Somehow, among the numerous activities that crowded the program, members found time to attend meetings of the various standing committees, to report their conclusions and recommendations to the important meeting of the Executive Committee, and finally to bring all pertinent matters before the annual business meeting of the Society. To accomplish this, the standing committees met at 4:00 p.m. on Wednesday and terminated their discussions before 6:30 p.m. when a special dinner was held for all committeemen. The Executive Committee met at 8:00 p.m., Wednesday evening, and continued, as usual, far into the early hours of the morning. Reconvening on Thursday afternoon, the committee was able to adjourn before evening.

With Society matters thus well organized in advance, the annual business meeting of the Society on Friday afternoon moved along very speedily. Among the main transactions to be reported were the approval of the new SESA By-Laws and the election of officers for the 1961–62 term. A notable event was the elevation of Treasurer W. M. Murray to Honorary President.

A moment of relaxation is enjoyed by President Drucker, Past-president Milton Leven and Executive Committee members C. E. Taylor and F. C. Bailey

As members of the Executive Committee go into session on Wednesday evening, a happy mood prevails. At the head table, left to right: Treasurer Murray, Vice-president Vigness, Executive Secretary Rossi, President Drucker and Vice-president Soroka

Details of the election appear elsewhere in EXPERIMENTAL MECHANICS. With the conclusion of several other matters, handled in swift succession, President Drucker rang down the gavel for adjournment of the meeting, and the First International Congress on Experimental Mechanics came to an end—a successful and well-conducted affair.

Typical scenes at the 1961 Exposition

New York Section Applauded

Before the members went their respective ways, everyone joined in a rising vote of thanks to the Metropolitan New York Section whose labors made the Congress possible.

Complete listing of national and local committees is as follows: *Organizing Committee*—D. C. Drucker,

chairman; W. M. Murray, honorary chairman; V. L. Salerno, G. Gerard, E. Wenk, Jr., M. M. Frocht, B. J. Lazan. *Advisory Group*—M. Hetenyi, N. J. Hoff, R. D. Mindlin and W. Ramberg. *Committee in Charge*—E. R. Lewis, chairman Metropolitan Section; V. L. Salerno, congress general chairman; D. L. Pasquine, congress vice-chairman; S. Black, secretary-treasurer, arrangements. Educational Program—S. V. Nardo, B. Erickson. Technical Sessions—E. L. Lewis, S. Black, E. Miller. *Exhibits*—T. Braunstein, L. Disenhof. Women's Program—Mrs. D. L. Pasquine, Mrs. S. Black. Ad-Hoc—G. F. Weissman, R. Hohenberg, A. Slobodzinski, I. Poss, C. H. Willer and D. L. Vidmark.

Getting some inside information from Banquet Speaker Emile J. Lapian, Indonesian Minister to the United Nations, are Congress Chairman V. L. Salerno, Executive Secretary Rossi, Mrs. Rossi and Mrs. Salerno. Past-president Lazan is in right background

At the banquet, the Metropolitan New York Section Committeemen had their first opportunity in several day to sit at dinner with their wives. The happy couples are (clockwise) Mr. and Mrs. E. R. Lewis, Mr. and Mrs. D. L. Pasquine, Mr. and Mrs. T. Braunstein, Dr. and Mrs. V. L. Salerno and Mr. and Mrs. S. Black

Minister Lapian addressing the group on the current problem of the U. N. Secretary-General

General view of the banquet

Honored guests at the banquet head table are Treasurer Murray, Honorary Member M. M. Frocht, Vice-president Vigness, Minister Lapian, President Drucker and Honorary Member Frank Tatnall

The W. M. Murray Lecture followed a special luncheon on Friday noon. Murray Lecturer Egon Orowan (inset) spoke of recent experimental findings in "The Structure of the Cold-worked Crystal"

Tired but happy, the New York Committee members prepare to close shop. Left to right, the faces now familiar to the hundreds attending the Congress: Don Pasquine, Ed Lewis, Sibby Nardo and Sig Black

IRWIN VIGNESS—PRESIDENT

W. W. SOROKA—VICE-PRESIDENT

C. C. PERRY—VICE-PRESIDENT

SESA Officers Elected for 1961–1962 Term

Five newly-elected officers to serve the Society for Experimental Stress Analysis during the coming term were introduced at the annual business meeting held at the close of the First International Congress for Experimental Mechanics on November 3, 1961, at the Hotel New Yorker, New York City. Retiring officers were highly commended for their handling of the many difficult tasks that arose during the past year.

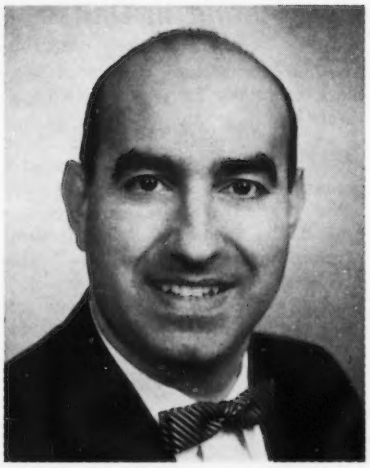
Vigness is New President

Elected to lead the Society for the 1961–62 term is Irwin Vigness who succeeds D. C. Drucker as president. Dr. Vigness, who is head of the shock and vibration branch of the Naval Research Laboratory at Washington, D. C., has just completed an active term as vice-president.

Filling the two-year post of vice-president is C. C. Perry, associate professor of engineering mechanics at Wayne State University, Detroit, Mich. As one of the two vice-presidents whose terms of office begin in alternate years, Prof. Perry moves up alongside Walter W. Soroka, of the University of California in Berkeley, who is now serving his second year.

Three members were elected to fill one-year terms on the Executive Committee. They are: R. A. Gallant, engineering laboratory director, Chevrolet Engineering Center, Warren, Mich.; D. Kececioglu, director of reliability and staff consultant, Allis-Chalmers Manufacturing Co., Milwaukee, Wis.; J. L. Walmsley, research department supervisor at Bethlehem Steel Co., Bethlehem, Pa. The newly-elected members of the Executive Committee replace three members who have left an enviable record of accomplishment. The retiring members are: Fred C. Bailey,

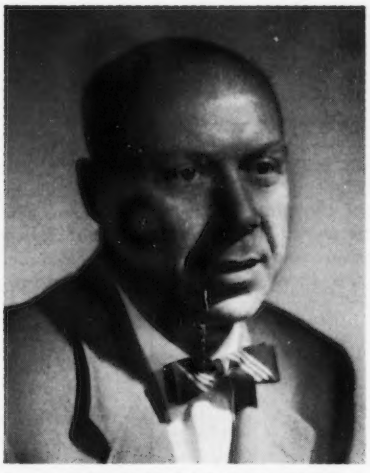
FRED C. BAILEY—TREASURER



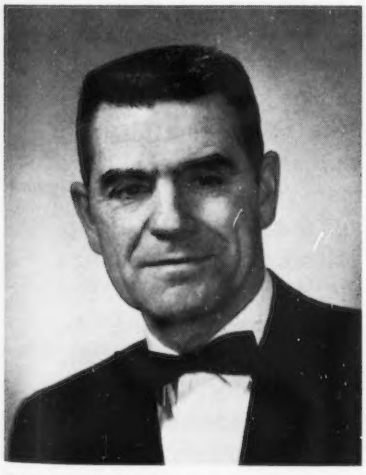
D. KECECIOGLU—EXECUTIVE COMMITTEE

W. M. MURRAY—HONORARY PRESIDENT

D. C. DRUCKER—EXECUTIVE COMMITTEE



B. J. LAZAN—EXECUTIVE COMMITTEE



R. A. GALLANT—EXECUTIVE COMMITTEE

J. L. WALMSLEY—EXECUTIVE COMMITTEE

president of Lessells and Associates, Inc., Boston, Mass.; John C. New, head of the test and evaluation div., Goddard Space Flight Center of the NASA, Greenbelt, Md.; and Charles E. Taylor, professor of theoretical and applied mechanics at the University of Illinois, Urbana, Ill.

Murray Made Honorary President

By a unanimous vote, the Executive Committee elected William M. Murray of MIT to the position of first honorary president of SESA. Dr. Murray who is one of the founders of the Society, and who for many years "has carried SESA on his own shoulders," was honored for this outstanding contribution to the field of experimental stress analysis.

Bailey Fills Treasurer Post

Mr. Bailey was appointed treasurer to fill the post previously held by Dr. Murray.

Ex-officio Members

The other members who will serve on the Executive Committee during the next year are—in addition to the regular officers—Past-president D. C. Drucker, Past-president B. J. Lazan and Executive Secretary B. E. Rossi.

Plans Unfold for 1962 Spring Meeting in Dallas

Members of the *South Central* Section of SESA have been busy with the numerous preliminary details connected with the forthcoming Spring Meeting to be held at the Hotel Sheraton-Dallas, Dallas, Tex., on May 16–18, 1962. Since the October 2 meeting of the local arrangements committee, previous tentative plans have been confirmed and extended. Dallas is a warm, friendly city and all reports indicate that "Big D" goes out of its way to make visitors feel at home—even those from the far, cold North. However, Dallas hospitality seems to have found an even match in the enthusiasm and energy shown by the *South Central* members to date. The following is a run-down on the status of arrangements.

Heading up the list of local personnel is General Chairman C. B. Franklin who with Vice-chairman J. R. Bos will have over-all responsibility for the Spring Meeting.

R. M. Shuffler is in charge of general arrangements. He will be assisted by J. W. Dalley and Roy Peterson. Their duties will include all the detailed hotel arrangements, such as, advance registration, registration-booth activities, meeting-room assignments for the various events and other details. The hotel has already reserved a large block of rooms for prospective registrants.

Word recently received from M. M. Lemcoe, chairman of technical sessions, indicates that plans are being carried out to group papers around the theme of "Experimental Mechanics in the Space Age." By special arrangement with the Society's Papers and Proceedings Committee, local sections may invite papers for a theme session. However, subsequent publication in the journal, EXPERIMENTAL MECHANICS, and in the *Proceedings* of the SESA can be secured only by due submission for review and acceptance by the Papers and Proceedings Committee. A new deadline for the regular submission of papers has been set for Jan. 1, 1962. Papers accepted by the local section for presentation at the theme session may be submitted at a later date.

Other local members who are working on phases of the program are: G. L. Thompson, who is making arrangements for local plant tours; Hudson Matlock, who is in charge of the seminars; B. P. Flowers, who is working on publicity and membership details. The banquet is under the direction of Bob Sandefer, exhibits under J. W. Dalley, women's activities under J. R. Bos, and finance under G. L. Thompson.

Second International Conference on Stress Analysis

The Second International Conference of Stress Analysis will be held in Paris at the Ecole Supérieure d'Aéronautique, from Apr. 10 to 14, 1962.

In principle, the number of contributions has been limited to 60, priority being given to original contributions of experimental nature. The languages admitted are English, French and German. Suggested papers must be sent to: Secrétariat du GAMAC, 2éme Conférence Internationale, 10, rue Vauquelin, Paris (5éme).

The title and a summary must be in one of the three languages (maximum two typed pages, black on white, prescribed size 21 x 27 cm) with an abstract in each of the two other languages (each abstract of maximum 10 lines each, both abstracts on the same page 21 x 27 cm).

If the contribution is accepted, the completed paper is to be sent before Feb. 1, 1962.

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DEADLINE EXTENDED FOR 1962 SPRING MEETING PAPERS

The new deadline for papers to be presented at the 1962 Spring Meeting, Dallas, Tex., is January 1, 1962. Authors unfamiliar with style requirements should write to SESA, 21 Bridge Square, Westport, Conn., requesting a copy of the pamphlet, "An SESA Paper." Manuscripts should be mailed to Dr. R. Guernsey, Chairman, Papers and Proceedings Committee, Space Technology Laboratories, One Space Park, Redondo Beach, Calif.

NEW SESA MEMBERS

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San Diego

Bright, Donald R.
Sunnyvale

Campbell, Douglas M.
Sacramento

Fitzgibbon, Donald P.
San Pedro

Horton, Wilfred Henry
Stanford

Salter, Larry
Palos Verdes Est.

Surland, Charles C.
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Teague, Mrs. Pauline V.
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Waterloo

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Saylak, Donald
Elkton

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Warren

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Lindh, DeVere V.
Larimer

Shore, Allen M.
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Sharples, Kenneth
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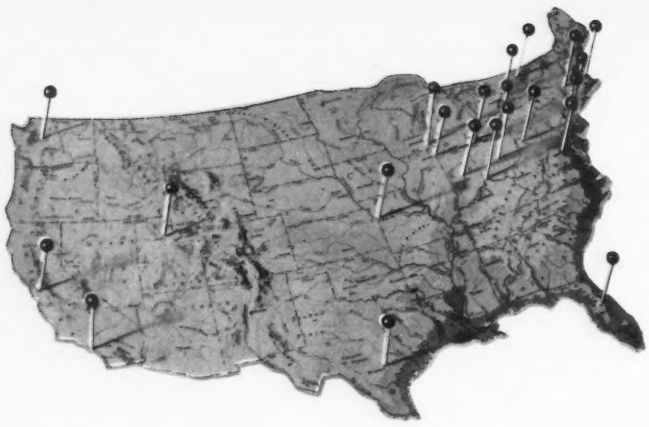
Shepherd, Robin
Christchurch, New Zealand

Tada, Yoshiaki
Tokyo-Kunitachi, Japan

Quarter Ending on September 30, 1961

Members	2118
Honorary Members	3
Corporate Members	90
TOTAL MEMBERSHIP	2211



section reports

Northern Ohio

Rand Explains Inventing Process

The season's kick-off meeting of the *Northern Ohio* Section was "refereed" by F. L. Main on October 2 at Pesano's with 80 members in the "backfield". The social hour and an outstanding prime rib of beef dinner were enjoyed by the entire "squad."

After presenting a certificate of appreciation to Past-chairman H. F. Calvert, the other new officers were introduced by chairman Main: G. A. Butz, vice-chairman, C. R. Schwallie, secretary and D. V. Langmeyer, treasurer. Plans for the season include a joint meeting with Detroit.

"An inventor takes a different viewpoint and then solves the problem." This philosophy has resulted in diversified achievements, at the Rand Development Corp., which were described by H. J. Rand, president. This firm has solved problems ranging from the elimination of clouding in tea to the development of an external heart massager. After fascinating the group by showing a film on small boat fabrication by spraying fiberglass, he mentioned several fields including methods for separating the constituents of animal cancer virus. Success in treating cancer in animals is expected to contribute to a large extent to the treatment of human cancer. The many questions that followed were a good indication of how well the talk was received.

The next meeting was scheduled for November 14 at the New York Central Research Laboratory.

(Reported by P. T. Chiarito for the Northern Ohio Section)

SECTION MEETING CALENDAR

EDITOR'S NOTE: Notices to be published in any one issue must reach SESA headquarters prior to the 15th of the second previous month. Give full information concerning date, time, place, topic and speaker for each meeting.

Southern Michigan

Sophisticated Strain Gages Discussed

The *Southern Michigan* Section opened its 1961–62 season on Thursday, September 21, at the McGregor Memorial Conference Center, Wayne State University. The meeting was well attended with 120 members and guests on hand. In addition to two lectures and a tour of the laboratory facilities of the Engineering Mechanics Department at Wayne State, diplomas were presented to participants of the stress-analysis course given earlier in September at the University. The two speakers for the evening were also lecturers at this course.

Calvin O. Vogt, project engineer of Century Electronics and Instruments, Inc., of Tulsa, Okla., was the first speaker. He presented a very interesting talk on "Piezoresistive Strain Gages."

The second speaker was James Starr, director of research, Allegany Instrument Co., Division of Textron, Inc., Cumberland, Md. His talk on "High-temperature Strain Measurement" was very well received by an attentive audience.

(Reported by Bob Keller for Southern Michigan Section)

OPENING MEETING HELD AT WAYNE STATE UNIVERSITY

First meeting of the season for Southern Michigan Section saw Dean Stuart Johnson of Wayne State University presenting diplomas to participants in the course on stress analysis sponsored by the Engineering Mechanics Department earlier in September

Speakers for the evening, James Starr (left) and Calvin Vogt (right) flank genial Mel Walck, program chairman for Southern Michigan Section.

Southwest

Annual Luncheon–Exhibit a Success

The Fourth Annual Strain Gage Equipment Exhibit and Luncheon sponsored by the *Southwest* Section was held on August 31, 1961, in the Satellite Room of the Miramar Hotel, Santa Monica, Calif.

A lively turnout of chapter members, guests and exhibitors attended the luncheon. The guests included members of the Western Regional Strain Gage Committee, representatives of Corporate Members of SESA, and students attending the current Strain Gage Lecture Course at the University of California at Los Angeles.

The exhibitors included Microsystems Industries, B. J. Wolfe Enterprises, Berggren & Co., Optron Corp., Dynasales, Rhodes Instruments, Microdot Inc., Neely Enterprises, Ormond Instrumentation Center, Allegany Instruments, Neff Instrument, "Bill" Bean, Video Instrument Co. Budd Co. and Aerojet General.

The SESA table exhibited special current editions of textbooks on experimental stress analysis published by Addison-Wesley Publishing Co., Academic Press and English Universities Press, Ltd.

The luncheon meeting was addressed by E. W. Larson, W. M. Murray, P. K. Stein and Sandford Friezner, section chairman, who introduced visiting guests and exhibitors. Each exhibitor then gave a brief description of his exhibit and equipment display.

After the luncheon, the exhibit area and well-appreciated bar were opened. Approximately 300 people working in the field of experimental mechanics attended. The Fourth Annual Exhibit and Luncheon was very well received by those attending, and the *Southwest* Section is looking forward to the Fifth Annual Strain Gage Exhibit and Luncheon to be scheduled in the Fall of 1962.

(Reported by E. W. Larson for the Southwest Section)

Washington Area

Publication Gets New Cover

The September 1961 issue of "Stresses and Strains," published by the *Washington Area* Section, started out the new year with a smartly-designed new cover. Crisply written and informative, the 16-page periodical carries news of local and general interest as well as advertising.

F. C. Falkenburg and J. L. Bachman are editor and business manager, respectively, for the present series—Volume 9—of this fine example of a first-rate section publication.

(C. H. Willer, SESA Headquarters)

AT SOUTHWEST'S EQUIPMENT EXHIBIT

Part of the lively turnout at the Southwest Section's Fourth Annual Strain Gage Equipment Exhibit held August 31 at the Miramar Hotel, Santa Monica, Calif. The six in conversation are, left to right: E. W. Larson, Jr., exhibit chairman; Judson Ferentz; W. M. Murray; Barry Wolfe; Lester Bierman; Sanford Friezner, Southwest Section chairman

Two of the many displays at the exhibit are shown in operation. Approximately 300 attended the exhibition following a luncheon during which each exhibitor gave a brief description of the equipment in his display. The event was coordinated with the SESA Strain Gage Lecture Course at the University of California at Los Angeles

MEMBERSHIP IN SESA

In the space age, measurements of stresses, forces and accelerations must be made to check calculations and to obtain information that cannot be calculated.

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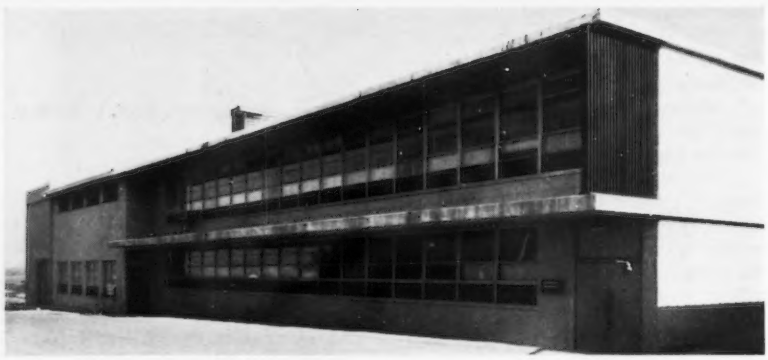

Engineering Mechanics Building, Southwest Research Institute

EISENHOWER AT CASE INSTITUTE

Former President Dwight D. Eisenhower visited Case Institute of Technology on November 9 as the principal speaker at a dinner-meeting which was described as "of national importance to higher education."

In describing the visit, Case Board Chairman Frederick C. Crawford said that General Eisenhower's visit was a great honor to Case Institute, especially at a time when it was beginning to emerge as a national leadership institution. Case Institute, in turn, had honored General Eisenhower by assembling a group of northern Ohio's most outstanding men and women, as well as other national leaders, to hear his remarks

Case President T. Keith Glennan said that the visit of General Eisenhower had made them justly proud. His brief, but intensive, experience as president of Columbia University had given him a special understanding and appreciation of the problems facing higher education today. He was well aware of the great importance of the contribution to our national well-being that must be made by educated professional manpower.

At Case Institute, Dr. Glennan continued, as a result of the generous and enthusiastic support of industry, alumni and other friends of Case, they had been able to rebuild their plant and double their educational facilities. They were now prepared to focus attention on the further development of faculty, educational, and research programs. They fully expect to carry their share, and more, of the responsibility for educating young men and women for effective participation in the solution of many of the grave national problems which General Eisenhower had discussed.

MEASUREMENT COURSES FEATURE BANQUET TALK

Israel Goldiamond, professor of psychology at Arizona State University, is the featured speaker at the banquet to be held Monday evening, Jan. 24, 1962, the opening day of the "Measurement Engineering Short Courses" given at Arizona State through Feb. 2, 1962.

The title of Dr. Goldiamond's address is "Measurement and Control of Human Behavior." Dr. Goldiamond is a graduate of Chicago University and has research and consulting contracts with a number of organizations including the Air Force Cambridge Research Center. He is one of the school of psychologists who believe that human behavior can be thought of as a product of our past experiences and the consequences of our present behavior. He has proposed an interesting theory of the scientific approach to psychology, and his talk will cover methods of measuring human behavior, and through measurements, its control.

The purpose of the short courses is to present the science of measurement in a logical and orderly manner. The courses consist of a lecture program and a concurrent experimental program. About one half of the lectures concentrate on the basic physical principles on which transducers are based and on fundamental measurement theory including static- and dynamic-system behavior and the correlation between them. Particular emphasis is placed on the interaction between system components and on how measurement systems are properly planned and designed. The other half of the program is devoted to measurement problems and approaches in specific areas.

The speakers have been selected for their complete familiarity with both the theoretical and practical aspects of their special fields, and for the contributions which they have made to advance the state of their own art. Registration lists close on Jan. 19, 1962. Contact Prof. Peter K. Stein, Engineering Center, Arizona State University, Tempe, Ariz., the director for the short courses, for further information.

RESEARCH AT CORNELL

More money was spent on research at Cornell University during the 1960–61 fiscal year than in any year in the University's history, according to John W. Hastie, coordinator of research.

Despite an essentially unchanged volume of research at Cornell Aeronautical Laboratory, Buffalo, the University's research expenditures increased 16.3% to the record figure of $39.4 million.

In the endowed colleges at Ithaca, the dollar volume of research appropriations has more than doubled. Mr. Hastie said that the startling change is due in major part to the large undertakings supported by funds from the Department of Defense related to two of Cornell's research centers. The work at Puerto Rico of Cornell scientists associated with the Radiophysics and Space Research Center, and the work on campus of the members of the Materials Science Center, account for much of the increase.

Percentage increases in the various fields of research endeavor at Cornell were: agriculture, 7.8; engineering, 304.5; humanities, 95.4; medicine and nutrition, 5.0; physical and biological sciences, 24.4; and social sciences, 16.7. There were decreases of 15.4% in veterinary medicine and of 5.3% in aeronautics.

The ratio of government support to the total research effort during 1960–61, in percent, was 66.9 from Federal contracts, 2.3 from Federal statutory, and 15.6 from New York State sources. The Federal government was the source of more than 90% of research funds at Cornell Aeronautical Laboratory.

NSF GRANT TO IIT ROUNDS OUT AID

Illinois Institute of Technology has received an institutional grant of $4,497 from the National Science Foundation to supplement existing budgets for the Institute's various research and research-training programs. This award, in contrast to other NSF grants for specific research projects, may be used by the school to help support any of its general research functions.

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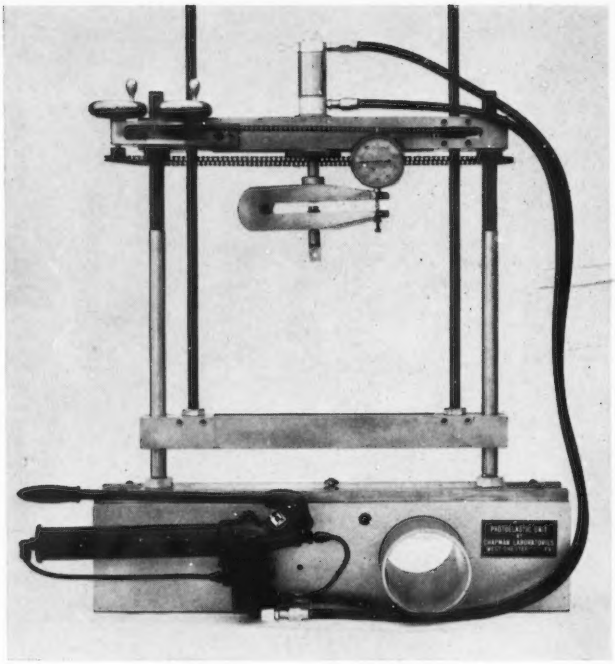

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Polariscopes — Model Making Kits

BOX 207

WEST CHESTER, PENNSYLVANIA

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MATERIALS AND STRUCTURES TESTING

Automated by electro-hydraulic system

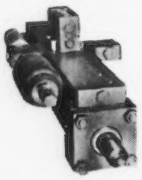
SERVO CONTROLLER

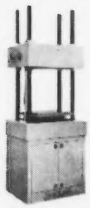
SERVAC generates signal for closed loop control of servo valves in dynamic load tests. Besides integrating the program, feedback, and bias control signals, it provides means for set-up calibration, tare adjustment and load cell excitation.

HYDR. POWER SUPPLY

CONTROL SIGNAL

ACTUATOR





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LOAD PROGRAM SIGNAL

LOAD FEEDBACK

MECHANICAL LOAD

PROGRAMMER

DATA-TRAK function generator follows pencil-drawn program curves to produce proportional potentiometer signals. Two-, and three-channel models have synchronized chart drums for simultaneously programming both temperature and load parameters. Various models offered.

LOAD CELL

TEST SPECIMEN

Examples:

Tensile Test Coupon
Aircraft Structures
Landing Gear
Missile Nose Cone

Any structure that is subjected to dynamic strength or fatigue tests from the simplest tensile test specimen to entire airframe structures. (Programs may vary from simple time vs load tests to complete load-temperature fatigue programs.)

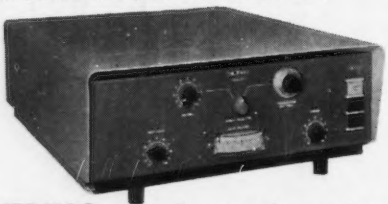
THERMO-COUPLE

TEMP. PROGRAM SIGNAL

TEMP. FEEDBACK

THERMAL STRESS

TEMP. AND POWER CONTROLLER

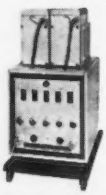


THERMAC precisely controls specimen temperature by proportioning power to heating equipment. Features include automatic thermocouple compensation, proportional band and rate limit adjustments. Single phase model shown has 40-amp capacity. Other models to 450-amps.

LINE POWER

POWER

HEATER



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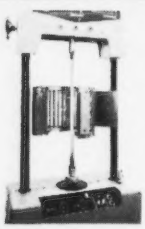

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